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SRI Technical Report No. 6

ATOMIZATION — A SURVEY AND CRITIQUE OF THE LITERATURE

Special Report

by

C. E. LAPPLE
J. P. HENRY
D. E. BLAKE

April 1967

DEPARTMENT OF THE ARMY
EDGEWOOD ARSENAL
Research Laboratories
Physical Research Laboratory
Edgewood Arsenal, Maryland 21010

Contract DA-18-035-AMC-122(A)

STANFORD RESEARCH INSTITUTE
Menlo Park, California

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FOREWORD

The work described in this report was authorized under Task 1B522301A08101, "Dissemination Investigations of Liquid and Solid Agents (U)." The work was started in March 1965 and completed in December 1966.

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DIGEST

A study was conducted to critically review and evaluate literature in the field of atomization. The literature survey yielded 955 pertinent references which have been summarized together with abstracts where available. The more important correlations presented in the literature for the various mechanical atomizing techniques (hydraulic or pressure, pneumatic or two-fluid, and rotary or spinning disk) have been summarized and analyzed. The best agreement was shown by the data for hydraulic swirl nozzles, where discrepancies were nominally not over twofold to threefold. The largest discrepancies, tenfold in some cases, were found for simple hydraulic nozzles. A large part of the discrepancy is attributed to shortcomings in the drop size analysis techniques, including sampling.

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I INTRODUCTION

The subdivision of a bulk liquid is commonly termed atomization. Atomization may also be used to subdivide solids if they can be melted as in the case of metals. Subdivision of a liquid (or a solid) may be desired for a number of reasons: (1) to permit distribution of materials throughout an area or space, (2) to expose a large surface for mass or heat transfer, (3) to provide desired flow, packing, optical, insulation, deposition, or other properties.

Because atomization is one of the processes involved in dissemination of liquid agents of solutions or suspensions of solid agents, a study was undertaken to critically review and evaluate the literature pertaining to this field. The first phase of this study was an exhaustive survey of the literature.

Although the literature survey revealed many reviews of the field of atomization [*e.g.*, Eisenklam (1961), Fraser and Eisenklam (1956), Fraser, Eisenklam, and Dombrowski (1957), Kim (1959), Marshall (1954), McIrvine (1957), Mugele (1960), Putman *et al.* (1957), Ranz (1956), Tate (1965), and Wolfe and Anderson (1964)], none was considered adequately comprehensive, nor were the results of various investigations presented on a particularly comparable or usable basis. The second phase of this study was therefore concerned with a detailed and critical analysis of the results of those investigators whose work appeared to be most important. This analysis was undertaken with the objective of summarizing available knowledge in the field of atomization in a self-consistent form to permit a direct comparison between the results of various investigations and to aid in the design of atomization equipment. The detailed analysis was limited to certain mechanical atomization techniques (hydraulic or pressure, pneumatic or two-fluid, and rotary or spinning disk—illustrated in Figs. 1-3). Some techniques (vibrational, explosive, and electrostatic) have been reviewed during other phases of the program, while others (gravitational and film bursting), although of importance in nature, would appear to have capacities that are too limited to be of interest in dissemination. These various techniques are summarized in Table I and are discussed in Section III.

In order to completely identify the performance of an atomization device it is necessary to specify the following items as a function of the operating conditions: (1) average size and uniformity (size distribution) of droplets produced, (2) power consumption, (3) liquid spraying capacity, and (4) operational considerations such as erosion or clogging. This study has been concerned primarily with the first of these, although the second and third items must be taken into account, if only indirectly. Certain general conclusions can be drawn on the relative merits of the various atomizing techniques from the standpoint of energy or power consumption. Capacity and operational considerations, however, are too intimately related to specific applications to permit generalized comparisons.

This report will cover only the intrinsic mechanical capabilities of techniques for producing fine drops. Any further reduction in drop size that can occur as the result of evaporation is beyond the scope of present considerations, since it involves other properties specific to each liquid.

II SUMMARY AND CONCLUSIONS

The literature survey yielded 955 pertinent references. These are listed in Appendix B together with abstracts where available. The scope of the most important investigations in the literature (covering hydraulic, pneumatic, and rotary atomizers) is summarized in Table II The detailed correlations presented by each investigator relating mean particle size generated to fluid properties and operating conditions are summarized in Tables III-V; in each table the data are presented in three formats. The first format gives the direct relationship. The second converts the relationship into a generalized dimensionless form. The third gives particle sizes predicted by the relationship for two velocity levels and the standard properties and conditions specified in Table VI.

For the standard properties and conditions the sizes predicted by the various relationships for similar atomizers cover a twofold and threefold range for the most part, with an extreme range of over tenfold in some cases. There are also very marked disagreements in the magnitude of the role played by each variable, with some investigators reporting inverted roles (*i.e.*, particle size decreases with an increase in the variable in one case and increases in the other case) for similar atomizers. The best agreement is shown by the data for hydraulic swirl nozzles for which the most extensive data are available. Good agreement exists for data on rotary or spinning disks. However, these data are relatively limited in extent. The greatest discrepancies are present in the data for simple hydraulic nozzles.

Some of the discrepancy can be attributed to the following: (1) many investigations covered only a narrow range of a variable, and hence had limited precision in assessing variations due to that variable; (2) some investigators did not actually investigate a variable but introduced it in the correlation for either rational or arbitrary reasons. The large discrepancies found with simple hydraulic nozzles suggest that turbulence, which is never reported or controlled directly, may be an important factor. It is believed however that a large part of the discrepancy is probably due to shortcomings in the drop-size analysis techniques, including sampling.

Although resolution is needed in most areas, data are particularly scarce in the following: (1) effect of gas density on atomization, especially pneumatic atomization, (2) effect of turbulence on atomization, (3) effect of compressibility in pneumatic atomization, (4) effect of ultrahigh pressure in hydraulic atomization, and (5) effect of high loadings (*i.e.*, representative of production capacities) on performance of rotary atomizers.

Although surface tension is an important variable, its effect on atomization is not sufficiently resolved. This is partially due to the small range (threefold) of variability in surface tension available with ordinary liquids. Although much larger surface tensions can be obtained by the use of molten salts and metals, very few investigators have employed them.

III ATOMIZATION TECHNIQUES AND MECHANISMS

A. Types of Techniques

Table I lists all the well known techniques by which liquids can be atomized. Like most attempts at categorization, it is not possible to develop a system in which each category is completely independent of another. In Table I the distinction between the various types of techniques is either in the geometry of the atomizing device or in the ultimate source of the external motivating force applied.

The first three categories (hydraulic, pneumatic, and rotary) are the mechanical techniques that are most widely used in industry, in agriculture, and in domestic applications. Figures 1, 2, and 3 illustrate various types of geometric devices that fall into each of those three categories. Vibrational and electrostatic techniques have received considerable attention in recent years, but they are still in a development stage. Explosive techniques have been widely used in military applications (chemical agent dissemination). Film-bursting and gravitational techniques are prevalent in nature but are normally not capable of atomizing liquids at high rates.

B. Basic Considerations

Essentially any atomization process can be considered as a disruption of the consolidating influence of surface tension by the action of internal or external forces or pseudoforces (such as inertia). In the absence of such disruptive influences, surface tension would act to pull a liquid into a spherical form (*i.e.*, a form with minimum surface energy). When opposed by other forces or liquid inertia, this action of surface tension can result in instabilities that will permit the bulk liquid to break up into smaller units. Any shear stresses set up within the liquid through the medium of liquid viscosity will resist a change in system geometry and hence will exert a stabilizing influence (*i.e.*, attenuate the disruption process). On the other hand, external shear stresses in the ambient medium may aid the disruption process by applying an external distorting force to the bulk liquid.

In order for any force to exert a disruptive action sufficient to produce particles of a desired fineness, the magnitude of the force must equal or exceed any consolidating action exerted by surface tension. One way to establish what types or magnitudes of forces are necessary to permit given degrees of atomization is to represent the various common types of forces on a comparable basis and to show the way in which these forces vary with drop size. This has been done in Fig. 4 where the various types of forces have been expressed in terms of a pressure corresponding to a variety of conditions. Surface tension has been expressed as an equivalent internal pressure set up within the drop. In order to produce a drop of a given size, it is necessary to exert an external force or action that will be at least as large as the surface tension effect. Since the system geometry and the relative direction and time of application of forces will also influence the details of any subsequent disruptive action or result, Fig. 4 cannot be expected to yield any rigorous quantitative comparisons. However, the figure is useful for demonstrating the ranges of utility and the necessary order of magnitudes for atomizing by various mechanisms. For example, the action of gravity alone might be expected to yield drops in the size range of several millimeters, but it would be incapable of fine atomization. A force field of 10,000 gravities (which can be achieved by rotary devices) would permit formation of drops in the 100-micron-diameter range. Drag forces due to the motion of a liquid relative to atmospheric air can yield drops in the size range of 10 microns provided the relative velocity approaches that of sound.

In a hydraulic nozzle, pressure energy is converted into kinetic energy of the liquid. If the motion of the liquid is changed in any way, the resulting inertial forces will tend to exert a disruptive influence. One might expect, therefore, that the maximum disruptive effect would be achieved by impingement of a fast moving liquid jet on an obstacle. On this basis one might expect that drops of the order of 10 microns in diameter could be produced by the use of hydraulic pressures somewhat greater than 10 psi, which would be the case if pressure differences of this order were set up over distances corresponding to the order of 10 microns. This, of course, requires much larger hydraulic pressures unless one starts with a sufficiently small diameter jet. It is more likely that the atomization from a hydraulically induced jet arises from the resulting drag of the surrounding atmosphere. In that case the hydraulic pressure acts primarily to set up a relative velocity between the liquid and the atmosphere. Hydraulic pressures of approximately 0.007, 0.7, 70, and 7000 psi are required to accelerate liquids having densities close to that of water to velocities of 1, 10, 100, and 1000 ft/sec respectively, ignoring possible energy losses in the energy transfer. Thus, to produce 10 micron drops would require hydraulic pressures of at least 7000 psi.

It is apparent from Fig. 4 that it is difficult to develop mechanical forces which are capable of overcoming surface tension in the submicron range. Sudden release of superheated liquids would be a way in which high disruptive internal pressures could be developed. Such releases, however, must be very rapid in order to minimize the attenuation of those disruptive pressures resulting from evaporative cooling. The actual process is a complex equilibrium between liquid acceleration due to internal pressures and relaxation of those pressures by heat transfer to the liquid surface. In addition to any pneumatic effects, this mechanism might be involved in explosive atomization.

C. Static Drop Formation

The most elementary form of atomization is the quasi-static case of the hanging or pendant drop. In its simplest form it is exemplified by the emission of a liquid at a very slow rate along a discontinuity, as in the slow discharge of a liquid from the end of a burette. When the action of gravity on the liquid exceeds the surface tension force along the discontinuous surface or wall, the liquid will be pulled away from the surface and a drop will form. For this type of slow emission of liquid from a thin circular tube, the mass of the drop formed is given by

$$m_p = \pi D_j \sigma_j / g_L \tag{1}$$*

The size of a spherical drop corresponding to this mass is given by

$$D_p = (6 D_j \sigma_j / \rho_j g_L)^{1/3} \quad . \tag{2}$$

The quasi-static breakaway of a liquid from a flat horizontal wetted surface involves a mechanism that is basically the same as that from a discontinuous surface, but one that involves a more complex balance of

* For definition of terms see section on "Nomenclature."

gravitational and surface tension forces. Based on the work of Tamada and Shibaoka (1961), the drop size formed by this mechanism is given by

$$D_p = 3.3(\sigma_j/\rho_j g_L)^{1/2} \quad . \tag{3}$$

From Equation 3 one would predict that drops, formed slowly by the action of normal gravity on a liquid film, would be 9 mm and 5 mm in diameter for water and organic liquids, respectively. By forming such drops from a 1-mm-diameter opening (with a discontinuous edge) instead of from a flat film, Equation 2 would predict drop diameters of 3.5 mm and 2.5 mm for water and organic liquids, respectively. If the hole size were reduced to 1 micron in diameter, the predicted drop size would be one tenth as large, or 350 and 250 microns, respectively. Thus the case of either the hanging or the dripping drop in a gravitational field involves production of relatively large drops at low rates. Although this mechanism is common in nature, it is not very effective when extensive atomization is desired, from the standpoint of either capacity or drop size. Gravity is a major factor only as long as forces due to hydrostatic head within the confines of a potential drop are sizable as compared with other forces. Thus gravity becomes a less significant factor in atomization as drop size decreases, and it becomes a negligible direct factor for producing drops smaller than 500 microns in diameter. Synthetic gravitational fields (such as centrifugal fields) that are much more powerful than ordinary gravity, however, can play an important role in fine atomization. Such fields are encountered with the spinning disk and will be discussed later.

As the rate at which liquid is fed to the hanging drop becomes appreciable, the breakaway is no longer the result of a quasi-static force balance. Both liquid inertia and kinetics then play an increasing role and the role of gravity becomes smaller.

D. Kinetic Drop Formation

The practical application of the atomization process requires that droplets be produced at some predetermined rate. This means that liquid must be supplied at some finite rate and continuously converted into droplets. The kinetics of all such atomization processes involve the following sequential steps, although any specific step may be negligible or absent under some circumstances:

1. The extension of a bulk liquid into sheets, jets, films, or streams by accelerating the liquid in some prescribed manner (as through a nozzle or off a rotating disk).

2. The initiation of small disturbances at the liquid surface in the form of local ripples, protuberances, or waves.

3. The formation of short ligaments on the liquid surface as the result of fluid pressure or shear forces.

4. The collapse of the ligaments into drops as the result of surface tension.

5. The further breakup of the drops as they move through the gaseous medium by the action of fluid pressure or shear forces.

The pendant drop previously discussed is a unique case for which the first and fourth steps alone are appreciable at negligibly low liquid rates. For this case only a balance between the gravitational field and surface tension is involved. As soon as fluid rates become significant, fluid inertia plays a major role, together with any of the other forces arising as the result of the fluid motion, and those forces introduced to achieve fluid motion (such as pressure and shear). The last step involves a unique limiting situation which will be treated separately in the next section.

There have been numerous attempts to theoretically analyze the kinetics of the atomization process. The most significant early work is that of Rayleigh (1878). This and the contemporary work have been summarized by Putman *et al.* (1957). Although this theoretical work has been useful in understanding the atomization process, it has not yet provided a quantitative description that can be used to design and predict performance of spray systems. Because of this a large amount of experimental data has been accumulated in the form of empirical correlations, which will be considered in a subsequent section.

Although the atomization process may involve all five specific steps mentioned above, it is usually possible to consider the atomization in only three stages. The first stage is that in which the fluid is brought to a point of initial breakup (and would comprise a combination of Steps 1, 2, and 3 above). The second and third stages would comprise Steps 4 and 5, respectively.

For the first stage, Miesse (1955) gives the following relationship as representative of the distance that a single hydraulic jet travels in stationary gas before breakup occurs:

$$L_b = \frac{102.8 D_j^{7/8} u_j^{3/8} \rho_j^{1/2} \mu_g^{5/8}}{\rho_g^{5/8} \sigma_j^{1/2}} \quad . \tag{4}$$

The actual data from which this relationship was derived showed considerable scatter. This equation can be written in a dimensionless form as

$$(L_b/D_j) = 102.8 \frac{(D_j u_j^2 \rho_j/\sigma_j)^{1/2}}{(D_j u_j \rho_g/\mu_g)^{5/8}} \quad . \tag{5}$$

For the standard fluid and nozzle properties listed in Table VI, (L_b/D_j) would range from 43.4 to 102.8 for velocities, u_j, of 1000 and 10,000 cm/sec, respectively, according to this relationship. These values would correspond to breakup lengths, L_b, of 4.34 and 10.28 cm, respectively.

Miesse (1955) presents the following relationship for the maximum drop size produced in the primary breakup of a jet from a simple hydraulic nozzle:

$$\left(\frac{D_{pmax}}{D_j}\right) = \frac{23.5[1 + 0.0000168(D_j u_j \rho_j/\mu_j)]}{(D_j \rho_j u_j^2/\sigma_j)^{1/3}}$$

$$= \frac{23.5[1 + 0.0000168 N_{Rejj}]}{N_{Wejj}^{1/3}} \quad . \tag{6}$$

This equation is based on limited data for a jet discharging into atmospheric air. Other data for discharge into air at high pressures showed somewhat smaller diameters that those that would be predicted from the above equation; data on injection into a low density atmosphere gave a somewhat larger value of drop size.

The third atomization stage involves the secondary atomization of drops produced in the primary breakup of the jet. This will be discussed in the next section. The overall atomization produced by the effect of all of the stages will be discussed in the section on bulk liquid atomization.

Doyle, Mokler, and Perron (1962) have derived the following relationship to express the particle size to be expected from ultrasonic atomization:

$$D_{xx} = C_{DM} \left[\frac{4\pi C_{DM1} \sigma_j}{\rho_j f^2} \right]^{1/3} , \tag{7}$$

where C_{DM} is a constant that measures the fraction of the total surface-wave cone height decapitated in the atomization process and C_{DM1} is another constant that measures the ratio of cone height to diameter. The authors suggest values of 1/2 and 1 for C_{DM} and C_{DM1}, respectively.

In ultrasonic atomization, the drop size is determined primarily by the frequency of the oscillation imposed on the liquid. The quantitative effect of frequency in determining drop size is illustrated by the accompanying values calculated from Equation 7 for the atomization of water (σ_j = 72 dynes/cm and ρ_j = 1 g/cu cm). It is not the intent of this report to analyze the area of ultrasonic atomization in detail; the above is presented only as a basis for comparison with other atomization techniques.

FREQUENCY, f (cycles/sec)	PARTICLE DIAMETER, D_{xx} (microns)
10^3	483
10^4	104
10^5	22.5
10^6	4.83
10^7	1.04

IV SINGLE DROP BREAKUP

When a droplet is moving through a fluid, there will be imposed on the surface of the drop both a pressure and a shear distribution. The integrated result of both of these is usually termed total drag on the droplet. As a result of the pressure distribution, the drop will become deformed, assuming a shape such that surface tension will compensate for the pressure variations. The shear will induce a circulation of liquid within the drop, and as a result of this circulation the pressure distribution will change. If the pressure variation becomes sufficiently great, there may be no stable shape that can compensate for the pressure variation, and the drop will deform indefinitely (*i.e.*, burst). Many authors [*e.g.*, Mugele (1960)] have indicated that this critical condition is achieved when the drag force just balances that of surface tension or when

$$F_D = C_D(\pi D_p^2/4)(\rho_g u_r^2/2) = \pi D_p \sigma_p \quad . \tag{8}$$

The terms may be rearranged to dimensionless form as follows:

$$(D_p u_r^2 \rho_g/\sigma_p)_{cr} = 8/C_D \quad , \tag{9}$$

where the subscript "cr" has been added to indicate that a critical condition has been achieved. The first term is the Weber number based on gas density, relative velocity, and particle diameter, and Equation 9 may be written as

$$(N_{We_g})_{cr} = 8/C_D \quad . \tag{10}$$

By solving for D_p, Equation 9 may be used to estimate the maximum drop size which is stable at a given relative velocity, u_r

$$D_{p\,max} = 8\sigma_p/C_D \rho_g u_r^2 \quad . \tag{11}$$

By solving for u_r, the critical velocity at which a drop of size D_p will rupture is given by

$$u_{rcr} = \sqrt{8\sigma_p / C_D \rho_g D_p} \quad . \tag{12}$$

Actually Equation 8 (and consequently Equations 9-12) cannot be derived on a rigorous basis, and can be considered only a crude approximation. Equation 8 basically assumes that the droplet is spherical and that the drag is all a form (pressure) drag that results in a corresponding increase in internal drop pressure. Equation 8 is basically the locus of all points of intersection of the curves for equivalent pressures due to drag and surface tension forces shown in Fig. 4.

In the actual case the drop will deform significantly from a spherical shape and will contain induced internal circulations long before the unstable condition is reached. Actually, because the drag coefficient is usually defined in terms of the projected area of a sphere having the same volume as the drop and because form (pressure) drag is usually predominant, Equation 8 gives a better approximation than might otherwise be supposed. At Reynolds numbers ($D_p u_r \rho_g / \mu_g$) greater than 1000, C_D is approximately 0.4 for solid spheres. However, when C_D is expressed in terms of the projected area of an equivalent sphere, it is found to range predominantly from 0.8 to 1.1 for drops at Reynolds numbers greater than 1000 [Nottage and Boelter (1940), Hughes and Gilliland (1952)]. This is due primarily to the greater drag force resulting from the drop deformation (flattening).

Lane (1951) found two types of breakup when drops were exposed to high velocity gas streams. The first, termed "bag breakup," was encountered when a drop was exposed to a gradually increasing gas velocity. Under those conditions the drop becomes increasingly flatter. At a critical relative velocity, the drop is blown out in a concave manner to form a hollow bag attached to a roughly circular rim. Bursting of this bag produces a shower of very fine droplets, while the rim, which contains at least 70 percent of the original drop mass, breaks up later into larger drops. The second type of breakup, termed "shear or stripping breakup," was encountered when the drops were subjected to abrupt, fast (transient) air blasts. In this case the drops presented a convex surface to the air flow, the diameter of the surface being approximately twice that of the original spherical drop. The edges of this saucer-shaped surface are first drawn out into a thin sheet, then into filaments that collapse to form fine drops. This type of breakup occurred at a somewhat lower average velocity than that encountered with bag breakup.

As pointed out by Ranz (1956), the critical Weber number $(N_{Weg})_{cr}$, is approximately 20 when the velocity is applied slowly (bag breakup) and 13 when the velocity is applied suddenly (stripping breakup) as in a shock front. These values apply as long as the viscosity of the liquid is low. Hanson, Dimoch, and Adams (1963) found that liquid viscosity had no significant effect on drop breakup by gas blasts as long as the kinematic viscosity was less than 10 centistokes. In the range of 10 to 100 centistokes, the critical velocity for breakup is increased substantially (*e.g.*, 70 percent for breakup of a 150-micron diameter drop having a kinematic viscosity of 100 centistokes). At the high kinematic viscosity the effect on critical velocity becomes greater as the drop size decreases. These studies also indicated that the critical gas velocity for drop breakup in a shock tube may be more nearly proportional to the cube root of liquid surface tension than to the square root implied by a critical Weber number (Equations 10 and 12). They suggest that breakup may be a function of a critical value of the product of Reynolds and Weber numbers

$$[i.e., \ (N_{Weg} N_{Repg})_{cr} \ = \ (D_p^2 u_r^3 \rho_g^2 / \sigma_p \mu_g)_{cr}] \quad .$$

For liquids with kinematic viscosities of 10 centistokes or under, they found that $(N_{Weg})_{cr}$ ranged from 9.6 to 15.9, while $[N_{Weg} N_{Repg}]_{cr}$ ranged from 5040 to 8940. For liquids with kinematic viscosities of 50 to 100 centistokes, $(N_{Weg})_{cr}$ ranged from 20.8 to 47.6, while $[N_{Weg} N_{Repg}]_{cr}$ ranged from 13,700 to 29,400.

Ranz (1956) indicates that atomization ceases because of liquid viscosity when the group $\mu_p^2 / D_p \rho_p \sigma_p$ is greater than 4. This group is the Ohnesorge number, N_{Ohp}.

Hinze (1955) suggests that the critical Weber number for a high viscosity liquid can be obtained from the critical Weber number for low viscosity liquids by multiplying the latter by a correction factor, $k_{\mu p}$, which is a function of the group N_{Ohp}. He presents graphical data for viscous drops suddenly exposed to an air stream. Those data can be closely approximated by

$$k_{\mu p} = 1 + (\mu_p / \sqrt{D_p \rho_p \sigma_p}) = 1 + N_{Oh\,p}^{1/2} \quad . \tag{13}$$

Thus, for D_p = 150 microns, μ_p = 100 cp, ρ_p = 1 g/cu cm, σ_p = 72 dynes/cm, the value of $k_{\mu p}$ = 1.96. This would correspond to a 40 percent increase in critical breakup velocity, which is somewhat less than that reported by Hanson *et al.* (1963) for similar conditions.

In an experimental investigation of aerodynamic breakup of liquid drops, Hanson *et al.* (1963) found that, contrary to what Lane (1951) experienced, bag breakup always occurs in the transient case as well as in the steady case except when the gas velocity is greatly in excess of the critical value. They also report that, with some drops undergoing bag breakup, the bag develops a re-entrant portion, or "stamen," near its middle, which increases in length with time and which in some cases inverts the bag before breakup occurs.

The above provides some basis for predicting under what conditions a drop will undergo breakup. It does not, however, give any basis for predicting the size of the droplets resulting from the breakup. Wolfe and Anderson (1964) have derived the following relationship for the average drop size, D_{av}, resulting from the further aerodynamic breakup of a drop of size D_p when exposed to a relative velocity, u_r:

$$D_{av} = \left[\frac{96\sqrt{2}\,D_p^{1/2}\mu_p\sigma_p^{3/2}}{u_r^4\rho_p^{1/2}\rho_g^2}\right]^{1/3} = \frac{5.14 D_p^{1/6}\mu_p^{1/3}\sigma_p^{1/2}}{u_r^{4/3}\rho_p^{1/6}\rho_g^{2/3}} \quad . \tag{14}$$

This equation may be rearranged to the following forms:

$$\left(\frac{D_{av}}{D_p}\right) = \frac{5.14(\rho_p/\rho_g)^{2/3}}{\left(\frac{D_p u_r \rho_p}{\mu_p}\right)^{1/3}\left(\frac{D_p u_r^2 \rho_p}{\sigma_p}\right)^{1/2}} = \frac{5.14(\rho_p/\rho_g)^{1/6}}{\left(\frac{D_p u_r \rho_p}{\mu_p}\right)^{1/3}\left(\frac{D_p u_r^2 \rho_g}{\sigma_p}\right)^{1/2}} \quad . \tag{15}$$

The derivation of this relationship involved a large number of assumptions (drag coefficient assumed as unity; specific proportionality factors assumed in establishing fluid sheet thickness, breakup time, and shear stress; aerodynamic forces assumed large as compared with viscous or surface tension forces). Based on an initial drop diameter of 1 mm and the fluid properties specified in Table VI, D_{av} would be predicted from Equation 14 as 753 and 35.0 microns for relative velocities, u_r, of 1,000 and 10,000 cm/sec, respectively.

Dickerson and Schuman (1965) exposed a single drop to high velocity (shock) air streams and measured the rate of change of the drop mass. They reported the following correlation:

$$\frac{u_s}{u_r} = \frac{3.53 \times 10^{-5} D_p^{1.38} u_r^{0.96} \rho_p^{0.4} \rho_g^{0.98} \sigma_p^{0.42}}{\mu_p^{1.8}}$$

$$= 3.53 \times 10^{-5} \left(\frac{\rho_g}{\rho_p}\right)^{0.98} \left[\frac{N_{Rep}^{1.8}}{N_{Wep}^{0.42}}\right] , \tag{16}$$

where the droplet mass loss rate has been expressed as an equivalent surface regression velocity, u_s [defined as $(1/2)(dD_p/dt)$]; and N_{Rep} and N_{Wep} are Reynolds number and Weber number, respectively, based on drop diameter, drop properties, and relative velocity. The apparent regression velocity was obtained from the rate of change of particle mass. The latter was determined from observed values of drop velocity, acceleration, and diameter as a function of time, although details are not given. It appears that this determination was predicated on arbitrarily assumed drag coefficient relationships. Since these themselves would be variable, subject to the specific distortions exhibited by the droplet, the validity of such a measurement is questionable. The test conditions involved a single liquid (RP-1-kerosene), a single gas (nitrogen), and two gas flow rates and densities.

Corcoran (1960) suggests that the Bond number ($\rho_p g_L D_p^2/\sigma_p$), previously introduced by Bond and Newton (1928) in connection with the rate of rise of bubbles in liquids, would give a better criterion for the breakage of an accelerating drop than would the Weber number. The Bond number is essentially the ratio of hydrostatic pressure in a drop to surface tension pressure. While this may be applicable for the breakup of very large drops (> 1 mm), it is unlikely that the Bond number is applicable to fine atomization. The Bond number could also apply to cases in which acceleration is due to forces other than gravity, by replacing "g_L" with "a." Normally, however, any drop acceleration will actually be a drop deceleration due to the action of drag forces. In that case the Bond number would be reduced to a combination of the Weber and Reynolds numbers.

V BULK LIQUID ATOMIZATION

It is the purpose of this section to present, summarize, and evaluate the available knowledge on the continuous atomization of bulk liquids by a variety of mechanical processes. For convenience these data have been grouped into categories similar to those outlined in Table I: hydraulic, pneumatic, and rotary. Because of the extensive data available on hydraulic techniques, these have been further subdivided into three classes: simple jets, impinging jets, and swirl jets. Table II gives a summary of all the investigations covered together with the range of conditions employed by each investigator.

The data on hydraulic, pneumatic, and rotary techniques are presented in Tables III, IV, and V, respectively. Table III is split into three parts (A, B, and C) to cover each one of the three classes of hydraulic techniques.

The considerations involved in presenting and analyzing these data are presented below together with a discussion of their overall significance and use.

A. Manner of Data Presentation

In making an analysis of atomization data it would be desirable to summarize and compare all available basic experimental data. This is, however, difficult for three reasons: (1) most literature reports of investigations do not present basic data in a sufficiently complete form to permit direct comparison with other data; (2) the available data are so extensive that a reconsideration of individual data points would be a monumental task; and (3) many data could not be compared directly because of intangible or intrinsically irreconcilable differences in methods of operation or measurement. Therefore, instead of comparing specific data, the various correlations of data that have been presented in the literature have been summarized. The results of other investigations that were not extended to the point of a correlation have been used only to establish specific points. Because of the extensiveness of the literature it was not possible to be comprehensive. However, it is believed that all of the more important investigations have been covered.

Each correlation was presented, where possible, in three formats. The first was a direct equation relating average particle size to geometric and operating variables, the relationship being presented in a standardized nomenclature but in a form as near to that used by the author as possible. In the second format, the equation was manipulated into a generalized dimensionless form. The basis for this format will be discussed below. In the third format, values of average particle diameter were calculated from each correlation for arbitrarily chosen standard fluid and nozzle properties and for two velocity levels. These standard properties are specified in Table VI and approximate a reasonable representation of practical ranges of operating conditions.

The first format gives a direct representation of the importance of each geometric or operating variable on average particle size. The second format is an attempt to provide a generalized comparison of the correlations on a mechanistic basis. The last format provides a direct simple comparison of what each correlation would predict for a specific practical operating condition.

B. Expanded Relationship

In the expanded relationship the original format of the correlation presented by the author has been preserved insofar as possible. In some cases algebraic substitutions of equivalent quantities have been made. In cases where correlations have been given by the author in terms of pressure drop, this fact has been retained. However, in those cases, an additional conversion in terms of velocity is also shown. This conversion involves a direct algebraic substitution of equivalent quantities.

In a few cases the author presented a complex mathematical correlation that would not lend itself to manipulation into the "Generalized Format." In most of these cases it was apparent that a simple exponential format would have fitted their data just as well. In those cases this alternative equivalent correlation was given even though that format was not presented by the author. The degree of equivalence to (or discrepancy from) the authors' original equation can be assessed by comparing the particle size values predicted from each equation for the standard conditions.

In many cases the authors have introduced variables into their correlations which they did not actually vary. In some cases this was justifiable on grounds of dimensional reasoning; in other cases it was completely arbitrary and unjustified. In all cases the expanded relationship is given as reported by the authors, and no attempt has been made to remove irrelevant or unjustifiable variables. In many cases it was impossible to make such a decision on the basis of the material presented. In a few cases, the author left out a variable because he actually varied it and found that it had no significant effect. In those cases that variable has been identified in the expanded relationship by an exponent of zero.

Some investigators [Kuznetsov and Tslaf (1957), and Tanasawa and Toyoda (1955)(1956)] have arbitrarily introduced a Froude number into their correlations. However, they did not vary the force field, g_L, and covered an insufficient range in the other variables to either establish or disprove the role of the Froude number. It is difficult to conceive that gravity could have any significant effect as compared to the effects of other forces over most of the ranges covered.

In some cases semantic problems and presumed typographical errors could not be resolved—these are noted in the tables. A major inconsistancy in the comparisons is the method of expressing average particle size. Most investigators used the Sauter mean diameter, D_{32}, for expressing average particle size; several used volume (or mass) median diameter; and some used a variety of averages or did not specify which average was used. Since sufficient data is rarely given on size distribution, it was not possible to convert average size to a consistent comparable basis. Instead, the type of average reported by each investigator is indicated in the tables. As a rule, the volume or mass median diameter will be larger than any other common average diameter. The Sauter diameter will be somewhat smaller (say 30 to 50% smaller for most practical conditions). Linear average diameter or number median diameters can be very much smaller than either the Sauter or mass median diameter.

It should be recognized that particle size analysis is still very much of an art. When applied to sprays, the added problem of representative sampling may introduce major additional errors, especially for the larger particles. Problems of evaporation can lead to major errors in reporting the finer particles. Thus the question of obtaining a representative absolute size analysis is one which compounds the problem of type of average size specified.

Sampling a spray for analysis involves many difficulties. Direct sampling poses problems of both withdrawing a representative sample of drops and maintaining the drops unchanged (*i.e.*, without deposition of the larger particles on the sampler walls). While *in situ* measurements (as by direct photography) can avoid the direct errors from sampling, they may introduce a more subtle, and often unrecognized, error. There are basically two types of *in situ* measurements: (1) measurement of particles or drops existing at a given instant in a volume of gas; (2) measurement of particles or drops passing through a given plane. These two measurements will yield the same result only if the velocities of all the particles are the same in magnitude and direction (and if one ignores any separate problems that can arise as the result of spatial variations in size distribution). In the general case it is necessary to have a knowledge of the velocity of each particle in addition to a knowledge of its size if one wishes to convert from one type of *in situ* measurement to another. To establish the nature of the spray produced by a given nozzle, it is necessary to make a measurement of the second type. For this purpose a measurement of the first type would yield a size distribution which is biased toward the slower moving particles. Some investigators, however, have used a measurement of the first type and assumed it to be representative of the spray produced. A measurement of the first type yields the actual distribution of sizes existing in a volume and would be the desired measurement for defining cloud or plume properties or for expressing phenomena that some other entity (body, wave, or beam) would experience when passing through the space at speeds high compared to those of any of the particles.

C. Generalized Format

The degree of atomization achieved by the various mechanisms can be expressed in the following form, as developed in Appendix A from dimensional considerations:

For hydraulic and pneumatic nozzles,

$$(D_{xx}/D_j) = k/N^{\alpha}_{Rejr}N^{\beta}_{Cajr} = k/N^{\alpha-\beta}_{Rejr}N^{\beta}_{Wejr} \quad ; \qquad (17)$$

For rotary or spinning disk atomizers,

$$(D_{xx}/D_d) = k/N^{\alpha}_{Rejd}N^{\beta}_{Cajd} = k/N^{\alpha-\beta}_{Rejd}N^{\beta}_{Wejd} \quad . \qquad (18)$$

Here the dimensionless numbers are based on liquid properties, a characteristic dimension, and the relative velocity between the liquid and the gas into which it is atomized (or disk tip velocity in the case of a spinning disk).

In Appendix A it is shown that, if the atomization is not influenced by gravitational or compressibility effects, then k will include only effects associated with relative properties of the gas phase and nozzle geometry. Gravitational effects could be significant only at very low relative velocity and for large drops. With spinning disks the centrifugal effect, which is the counterpart of the gravitational effect with hydraulic and pneumatic nozzles, is important. However, for that case the equivalent Froude number is not an independent variable, and the centrifugal effect may be allowed for by the combination of any of the other pairs of dimensionless groups, such as Reynolds and Weber numbers. Compressibility should be a factor only in the case of high pressure pneumatic atomizers. Since there is little reason to believe that gas viscosity will play any major role (except possibly for very fine drops), the factor k can, for the most part, be expected to include only a measure of nozzle geometry and of the density of the gas relative to that of the liquid in hydraulic or spinning disk atomizers. With pneumatic atomizers, the term k would also include a measure of the loading (liquid-to-gas ratio) and of compressibility at the high air pressures.

In order to provide a common basis for comparing the correlations proposed by the various investigators, each relationship has been manipulated into the form dictated by Equations 17 and 18. There are, in general, many ways in which the correlations can be manipulated depending on which terms are to be excluded from k. The procedures governing these algebraic transformations are given in Appendix A. If all the investigators had covered all the variables without errors in any of the measurements, all such transformations should yield the same final format (or multiple formats). Actually, most investigators did not vary all the factors reported as variables and they probably had some inherent errors in their measurements. In addition, many investigators, on the bases of an arbitrary opinion, introduced quantities that were not varied into their correlations. Since the quantity (or its equivalent in terms of dimensional analysis) was not varied, there exists no basis for establishing the validity of such an arbitrary introduction. This is especially true in some of the Russian literature where the Froude number is given great prominence for no apparent reason.

In making a transformation to a common format, it is reasonable to concentrate on those quantities which were varied most widely. Surface tension was rarely varied over more than a threefold range (from 25 dynes/cm for hydrocarbons to 72 dynes/cm for water) since there are but few data on molten metals or mercury, for which surface tension is upwards of 400 dynes/cm. Fluid velocity and viscosity lend themselves to the greatest variations. Nozzle size could also be varied widely, but practical considerations often dictated a range of less than threefold. Many investigators also tended to change geometry whenever they changed size.

In actually making the transformations to the common format, various bases were used for the results of the different investigators. While an attempt was made to choose the most widely varied quantities as the basis for the transformation, this was often not feasible because the author did not cover a reasonably wide range, did not specify his range, or varied his geometry in the process. In any event, the actual basis used is indicated in Tables III-V, and in many cases the transformation was made on more than one basis.

In transforming from the expanded relationship to the generalized format for hydraulic and pneumatic nozzles, the velocity term in the generalized format was based on the relative velocity, u_r . For each type of nozzle the definition of u_r given in the table of nomenclature was adhered to. For rotary (spinning disk) atomizers, the velocity term in the generalized format was taken as the tip speed of the rotor, u_d, which comes close to being the actual relative velocity between liquid and gas in most cases. With a vaned rotor the actual relative velocity will be somewhat larger than u_d due to any additional radial component resulting from the liquid flow. With a nonvaned rotor, the actual relative velocity may be less than u_d because of slippage between the fluid being atomized and the disk surface.

One might conclude that the most reliable investigation is one which yields the same, or reaches the same, final result when transformed to the generalized format on several different bases. This would be true if the investigator had actually varied all the variables independently in the experimental work. In most cases, however, this was not done and the correlation includes quantities that were not varied, these quantities having been introduced on the basis of dimensional reasoning similar to that used in Appendix A. In those cases, of course, agreement between various bases of transformation is preassured.

D. Particle Size Prediction

The standard properties and conditions were selected as unit powers of ten. This was done to permit easy extrapolation of the specific values given to any other fluid property or condition by reference to the exponential variation for that property or condition shown in the first format.

The fluid and nozzle properties specified in Table VI are common to all correlations. Two velocity levels were chosen for all predictions, 1000 and 10,000 cm/sec. Table VI also gives the value of various dimensionless groups and other quantities corresponding to these velocities and to the standard fluid and nozzle properties. Because some authors introduced additional factors into their correlations, it was necessary to set additional specifications for those cases. These additional specifications are given in the summary tables (III, IV, and V) for those investigations where they were needed.

For those cases where correlations have been presented by the author in terms of pressure drop, the conversion from pressure drop to velocity involved the terms N_{vj} and N_{vr}, as defined by the table of nomenclature. The term N_{vr} is a measure of the effectiveness with which pressure energy (pressure drop) is converted into kinetic energy of liquid relative to the gas into which the liquid is ejected. This value will usually be close to unity for all nozzles, differing therefrom only because of wall friction losses in the nozzle. Any losses will result in a value of N_{vr} that is larger than unity. The term N_{vj} relates pressure energy to kinetic energy as defined by u_j. For stationary axial flow nozzles, N_{vj} will be identical with N_{vr}, and both will be close to unity. For cases where u_j is not an actual velocity (as with swirl nozzles), N_{vj} may differ radically from N_{vr}. For a swirl nozzle for example, N_{vj} will probably be of the order of 10, ranging from 4 to 20 (the greater the relative magnitude of the tangential velocity component, the larger N_{vj}). To show what effect such a difference in N_{vj} would have the size prediction in the case of several correlations has been given for assumed values of N_{vj} of both 1 and 10. It should be noted, however, that N_{vj} is a specific number which is determined primarily by the geometry of the nozzle and is not subject to arbitrary choice. In those cases where N_{vj} appears in an author's correlation, it should probably be replaced with the actual value applying to that author's nozzle geometry for all equations that are expressed in terms of u_r.

In presenting the size predictions, the calculations have been based on the expanded relationship presented by the author. The same predicted size is obtained if the calculation is based on the generalized format, provided those variables comprising the "k" term are also given the values specified in Table VI.

An alternative method of prediction is possible, which consists of treating the "k" term as a constant on the grounds that the "k" term *should* be a constant and that the remaining variables in the "k" term reflect inherent errors in the author's correlations or measurements. As was previously indicated, this independence of k of other variables is a reasonable postulate, with the exception of any variable that might reflect the effect of gas density To obtain the "constant" value of k it is necessary to substitute for all variables comprising k in the generalized format the average value of each variable during the author's investigation. This value of k would then be treated as a constant in making any size predictions for other conditions. Such a method would probably yield a somewhat better value for the predicted sizes; it was not done here because of the difficulty of assessing representative average values for variables in some of the investigations.

E. Miscellaneous Data and Comments

It is generally agreed that gas viscosity has little effect on the atomization process. The data of Popov (1956) are especially conclusive on this score, since he varied his gas viscosity from that of neon (μ_g = 0.0311 cp) to that of acetylene (μ_g = 0.0102 cp) and found that drop size varied as the 0.08 power of gas viscosity (power ranged from 0.045 to 0.12) Considering that gas viscosity cannot normally be varied by more than a threefold range in practice, the variation of drop size due to gas viscosity cannot be over 10 percent.

De Corso (1960) reports that, for swirl nozzles discharging into a tank, the particle size (D_{32}) obtained is a minimum at a tank pressure of approximately 1 atm, as shown below:

Fuel Injection Pressure, psia	Value of D_{32}, microns for Tank Pressures		
	0.5 psia	14.5 psia	114.5 psia
25	206.5	150	213
100	106.6	75.2	109.9

De Corso explains this on the grounds that the coalescence of fine drops increases at the highest tank pressure because the spray is also confined to a smaller volume at the high pressure. It should be noted, however, that the spread in mean particle size, D_{32}, over the entire tank pressure range is only ±20 percent. Dombrowski and Hooper (1962) also report a similar trend of particle size (D_{32}) with tank pressure for impinging-jet nozzles. In their case the spread in particle size was only ±8 percent over the entire pressure range (28 in. Hg vacuum to 300 psig) with the minimum size occurring at a tank pressure of 10 atm.

Nelson and Stevens (1961) reported no effect on atomization when the nitrogen atmosphere, into which a swirl nozzle sprayed, was replaced with helium. They also reported that a smoother nozzle gave a somewhat finer spray.

Bitron (1955) is the only investigator who reports specific data on pneumatic atomization at supersonic velocities. Others [such as Wigg (1960)] may have operated at supersonic velocities but did not distinguish this fact in reporting their data. Bitron (1955), atomizing dibutyl phthalate with an external mix pneumatic atomizer (in which the air nozzle consisted of a de Laval nozzle), reported that the Sauter mean diameter, D_{32}, agreed within 15 percent of values predicted from the Nukiyama-Tanasawa (1939) equation at Mach numbers up to 2. It should be noted that his velocity increase was attained by going to a higher nozzle inlet gas pressure, rather than discharging into a lower downstream pressure. His data are summarized below.

RUN NUMBER	1	2	3	4	5
Nozzle dimensions,* mm					
Throat diameter	2.72	2.77	2.81	2.86	2.94
Mouth diameter	2.84	3.05	3.24	3.46	3.83
Upstream air pressure, atm. abs.	3	4	5	6	8
Air flow rate, g/sec	3.6	4.8	6.0	7.2	9.6
Liquid flow rate, mg/sec	3.3	4.4	5.5	6.6	8.8
Exit air velocity from nozzle, m/sec	460	520	570	620	680
Air temperature, °C					
Upstream	110	145	170	200	245
Mouth (calculated)	8	7	7	11	13
Sauter mean diameter, D_{32}, microns					
Measured†	7.2 (7.5)	7.0	6.6 (8.9)	7.3 (8.6)	5.7 (6.4)
Calculated [Nukiyama-Tanasawa (1939)]	7.2	6.3	5.7	5.3	4.8

* Convergent cone angle was 18°, divergent, 5°; Nozzle discharged to atmosphere in all cases

† Values in parentheses include single conspicuously large drops (25 to 42 microns) that were ignored in other values given.

F. Discussion

It is generally agreed that in a qualitative sense all the atomization mechanisms are similar for the various types of mechanical atomizers at the high capacities or velocities usually used for fine atomization (*i.e.*, once the region where gravitational effects are predominant is passed). There are, however, some basic differences between the various types of atomizers aside from specific differences in geometry. In the hydraulic (and rotary) nozzles, the liquid jet is accelerated back toward the liquid nozzle by the drag of the gas into which the liquid is ejected. In pneumatic nozzles, the liquid is accelerated away from the liquid nozzle by the gas drag. Therefore, one might expect that recombination of drops might be less significant with pneumatic nozzles than with hydraulic nozzles. With hydraulic nozzles turbulence is introduced through the liquid stream, thence by the liquid to the ambient gas. In pneumatic nozzles, turbulence is introduced through the gas stream even though it would be possible to introduce it through the liquid stream as well.

Since the correlations for all types of atomizing nozzles are expressed in terms of relative liquid-to-gas velocities, one might expect the correlations to be directly comparable. If atomization mechanisms were the same, one might even expect all the relations to be similar except for geometric factors. Factors such as those indicated above, however, can produce basic differences in mechanism and hence differences in the nature of the relationships between the various types of atomizing devices.

In Tables III-V the degree of agreement between the results of various investigators can be seen most readily by either of two approaches: (1) by comparing the exponents on specific variables in the expanded relationship for mean particle diameter or (2) by comparing the size predicted from each correlation at standard conditions (given in the two columns just preceding the "Remarks" column). Table VII has been prepared to provide a more convenient comparison of exponents by summarizing the exponents for each of the more important variables.

From Table VII it is apparent that the effect of the variables indicated by the various investigators differs greatly even to the extent of showing opposite trends (reversed sign of exponent). Part of this discrepancy is fictitious due to the fact that the experimenter did not actually vary a term but arbitrarily introduced it into his correlation

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as a variable. This is common for gas density and viscosity. Liquid density and surface tension can usually be varied over only a threefold range, that is, unless molten salts or metals are used. Practical considerations may also limit variations in nozzle size. Most investigators, however, could and did vary velocity widely. Even here a wide discrepancy is apparent, even within specific types of atomizers.

By comparing the size predicted for each correlation at each of two velocity levels in Tables III-V, it is apparent that the agreement is at best within a twofold to threefold range—some values varying by as much as a factor of over ten at a given velocity level. Part of this lack of agreement may reflect the fact that the correlation did not cover all the variables, and hence the correlation cannot be extrapolated safely. However, this effect should be minimal, since the standard conditions were chosen such that they would be close to or within the range of conditions used by most of the investigators. The one exception is the standard surface tension which was chosen as a round 100 dynes/cm, a value somewhat higher than would correspond to the surface tension of the liquids used by most investigators. However, since mean drop size at most would appear to be a square root function of surface tension, this difference in surface tension values could not account for even a twofold spread in the data.

It is likely that a large part of the differences between investigators may be attributed to problems in obtaining reliable drop size measurements. Considering the combined problems of representative sampling, possible evaporation, drop collection (where applicable), actual size measurement, and interpretation of data in terms of specific mean size, a twofold spread in mean reported drop size is not unlikely, and might be even greater. Other factors that could be involved represent intangibles, which were neither controlled nor reported, such as detailed geometry, especially upstream of the atomization point, and resultant turbulence levels in both liquid and gas streams.

In general, the best agreement in drop-size data appears to be for rotary or spinning disk atomizers. This agreement may be misleading, however, since there are relatively few investigations. Several of the correlations indicated in Table V are actually based largely on the data of Walton and Prewett (1949). These were data at very low liquid capacities where the rotary (spinning disk) nozzle is actually a centrifugal adaptation of the pendant drop. If the term g_L in Equation 3 is replaced with the acceleration in a centrifugal field, $u_d^2/(D_d/2)$, one obtains

$$D_p = 2.3(\sigma_j D_d/\rho_j u_d^2)^{1/2} \quad . \tag{19}$$

It will be observed that this equation agrees with most of the relationships given in Table V for the spinning disk for low atomization rates, even to the magnitude of the constant. This is especially interesting since the low-rate equations in Table V were derived primarily on theoretical grounds based on considerations of liquid jet stability in the presence of surface disturbances. At the standard conditions of Table VI, drop sizes of 730 and 73 microns would be predicted from Equation 19 for disk tip speeds of 1000 and 10,000 cm/sec, respectively.

Fraser, Dombrowski, and Routley (1963) and Friedman, Gluckert and Marshall (1952) conducted investigations in which higher liquid flow rates were used and in which the fluid dynamics might be expected to influence degree of atomization rather than the quasi-static considerations of a pendant drop. Fraser *et al.*, however, actually used a combination spinning disk and pneumatic atomizer which is unique in a geometric sense. Friedman *et al.*, covered a radial film Reynolds number (Γ_j/μ_j) range of 300 to 2800. At a low disk speed, the size predicted from their correlation is of the same order as predicted from the pendant drop-type of relationships; at the high disk speed, the drop size is considerably larger. However, the insensitivity of drop size to surface tension that they report appears unusual.

The second best agreement in the data of various investigations appears to be in the area of hydraulic swirl nozzles. These have actually been investigated more extensively than others because of their wide use in liquid fuel atomization. However, Turner and Moulton (1953) report a large effect for surface tension which is unusual as compared with the effect found by most other investigators. From a weighted average of all the data, the following is a reasonable representation of the performance of swirl nozzles (which is probably good to better than ±50 percent):

$$\frac{D_{32}}{D_j} = \frac{5.5}{(N_{Rejr})^{0.20}(N_{Wejr})^{0.25}} \tag{20}$$

or, by rearranging terms,

$$D_{32} = \frac{5.5D_j^{0.55}\mu_j^{0.20}\sigma_j^{0.25}}{u_r^{0.70}\rho_j^{0.45}} \quad . \tag{21}$$

For the standard conditions this equation would predict mean drop diameters of 155 and 31 microns at relative velocities of 1000 and 10,000 cm/sec, respectively. No formal evaluation was used to obtain Equation 20, the weighting being based on individual judgment of the merit of each investigator's result. Equation 20 also neglects any effect of the density of gas into which the liquid is sprayed. As will be shown later this effect is controversial but is probably small in this case.

The data for impinging jets show reasonable agreement but are not as extensive as the data for swirl nozzles. Mugele's (1960) relationship gives a reasonably good average representation.

The greatest disagreement appears to exist in the data for simple hydraulic nozzles. This is most apparent in comparing predicted sizes for the standard conditions. Although the disagreement is still great, the agreement is somewhat better if the fan spray data are considered separately. The very large sizes predicted from the relationships of some investigators using simple circular nozzles [Panasenkov (1951), Popov (1956), Tanasawa and Toyoda (1956), and Tanasawa and Kobayasai (1955)] stand out particularly. This might imply that turbulence of the liquid jet might play a predominant role in the degree of atomization. This is a factor which was practically never controlled or measured by the various investigators. With impinging jets and swirl jets, the nozzle geometry itself probably exerts an indirect control on turbulence. With a simple jet, however, any uncontrolled upstream turbulence might be expected to have a greater relative effect. Dombrowski and Hooper (1964) have reported major differences (one to threefold on particle size) in atomization with laminar and turbulent jets.

The effect of gas properties on atomization is an area in which there are comparatively few data. As mentioned in a previous section, the effect of gas viscosity is generally agreed to be very small. For hydraulic nozzles the effect of gas density appears to be variable but small. For pneumatic nozzles, however, the effect of gas density would appear to be large as indicated by the values given in Table VII. Even in those cases, however, the effect of gas density is not completely separate because gas density changes are usually accompanied by changes in compression ratio with resultant shock phenomena. Weiss and Worsham (1959) report an effect of gas density in terms of gas pressure. For the range of pressure covered by them, it can be shown that this effect is the equivalent of a +0.4 power on gas density insofar as the effect on mean drop size is concerned. Weiss and Worsham used an atomizing arrangement which might be construed as a combination of pneumatic and hydraulic atomization.

In the case of pneumatic nozzles there is considerable confusion concerning the calculation of the relative gas velocity. Some authors have calculated velocity based on measured mass flow rate and gas density calculated at atmospheric temperature and pressure, some have used sonic velocity (corresponding to the ambient temperature) for all pressure drops above the critical; others, like Bitron (1955), have apparently used isentropic expansion velocities; and some are ambiguous on this point. The effective gas density is similarly confused and unresolved. At the present time there are not sufficient data on atomization at high compresssion ratios to resolve the question. The problem is further complicated by the presence of shock waves in supersonic jets (or in underexpanded free jets). The effective gas density and velocity in such cases would also be expected to be different between internal and external mix nozzles. If the kinetic energy of the gas is the controlling factor, then the maximum value attained by the product $\rho_g u^2$ in the isentropic expansion of a gas may be a correct measure of the attainable atomization effect. This value occurs at an expansion slightly beyond that corresponding to the critical, which is required for sonic velocity to be achieved.

It is difficult to give a recommended equation for pneumatic atomization. Kim (1959), Mugele (1960) and Nukiyama and Tanasawa (1939) all seem to give results of the same order at the higher velocities. Wigg (1960) also gives reasonable results but on the finer side with respect to drop size. The effect of nozzle size on drop size is the most confused. Kim (1959) reports a marked effect of nozzle size but in the direction of reduced particle size when a larger nozzle size is used, which does not seem reasonable. Since in varying nozzle size he also varied other geometric factors at the same time, it is possible that the apparent role he assigns to nozzle size is actually a measure of another geometric factor.

The following two factors have a negligible effect at low values of the factor but become significant at high values: (1) liquid viscosity in hydraulic nozzles and (2) liquid-to-gas ratio, or liquid loading, in pneumatic atomizers. These factors could be allowed for in terms of a correction factor that approaches unity at low values of the factor. Simple functions that could be used for this purpose are $(1 + kx^{\epsilon})$, $(1 + kx)^{\epsilon}$, or $[\exp(kx^{\epsilon})]$, where k is a constant and x is a dimensionless group containing the factor. For the effect of liquid viscosity, x could be the Ohnesorge number, $N_{Oh_{jj}}$; for the effect of liquid loading, x could be either (w_j/w_g) or (q_j/q_g). Various investigators have used such factors but not as extensively as possible. Kim (1959) used the last of these functions (the exponential function) to extrapolate his raw data to zero liquid loading. He then expressed his final results, including the effect of loading, in terms of a function of the first type (power function added to 1) for reasons which were not indicated and are not apparent.

Some investigators have used loading factors as direct multiplicative power functions in expressing the effect on particle size [*e.g.*, Gretzinger and Marshall (1961) and Plit (1962)]. It is dangerous to extrapolate such correlations since they would indicate either a zero or an infinite size when extrapolated to a zero value of the factor. For example, the actual data of Gretzinger and Marshall show drop size becoming independent of loading for ratios (w_j/w_g) less than 0.1. Consequently, their correlation can only hold for loadings (w_j/w_g) greater than 0.1. In their case liquid loading and air gap clearance were not varied independently. Hence, some of the apparent loading effect could actually be a diameter or air-gap clearance effect.

Although size distribution in addition to mean size is an important factor, comparatively few data are reported on size distribution. Mugele (1960) gives a summary of such data. Many of the data are given as a ratio between two means or between a mean and the maximum drop size. Tanasawa *et al.*, (1955-57) report the maximum drop size as being two to three times the Sauter diameter. Friedman *et al.*, (1952) report that geometric standard deviations are mostly 1.4 to 2.0 for rotary atomizers. The widest range of sizes is probably produced by pneumatic nozzles and the most uniform by rotary atomizers. Hydraulic nozzles usually give a wide distribution of sizes but not quite as wide as pneumatic nozzles.

It is generally known [e.g., Marshall (1954)] that the efficiency of atomization is low (under one percent) in terms of the fraction of applied energy utilized in creation of new surface. Because of the wide spread in data on mean particle size for the various investigators, no further estimates have been made on relative power consumption in each case.

Rotary atomizers are basically hydraulic units in which the liquid pump has been combined with the nozzle. Consequently, one might expect that the power consumption for both hydraulic and rotary atomizers would be of the same order. In the case of rotary atomizers the additional power to overcome air friction would tend to be compensated for by a more direct application of energy to liquid with lower coupling or transmission losses. Pneumatic nozzles, however, will have a considerably higher power consumption because air must be accelerated in addition to the liquid. The lower air density, however, permits the attainment of considerably higher relative velocities without incurring the high pressures that would be necessary to attain a comparable velocity with a hydraulic nozzle.

The efficiency of a hydraulic atomizer can be expressed in terms of pressure drop as follows:

$$\eta_A = (6\sigma_j/D_{32})/\Delta p \quad . \tag{22}$$

This is obtained by taking the ratio of energy represented by the total surface area generated to the energy needed to elevate the pressure of the liquid by Δp. By substituting u_r for Δp,

$$\eta_A = 12\sigma_j/N_{vr}u_r^2\rho_j D_{32} = (12/N_{vr})/(D_{32}u_r^2\rho_j/\sigma_j) = (12/N_{vr})/(N_{Wep})_{32} \; . \tag{23}$$

where the subscript 32 indicates that the particle Weber number is based on the Sauter diameter.* Equation 23 can also be written

$$\eta_A = (12/N_{vr})(\rho_g/\rho_j)/(N_{Weg})_{32} \quad . \tag{24}$$

* The subscript j has also been assumed to be synonymous with p insofar as the drop properties are concerned.

Since N_{vr} differs from unity because of losses within the nozzle system, one could argue that a more basic assessment of atomization efficiency is to set N_{vr} equal to unity on the grounds that those losses are not directly part of the atomization process itself. Hence

$$\eta_A = 12/(N_{Wep})_{32} = 12(\rho_p/\rho_l)/(N_{Weg})_{32} \quad . \qquad (25)$$

Equation 25 would also hold for a rotary atomizer. As a first approximation one can assume that $u_r = u_d$.

For a pneumatic atomizer, assuming that all the energy is provided in accelerating or moving the gas phase, similar reasoning will lead to

$$\begin{aligned}\eta_A &= 12\sigma_l/[D_{32}u_r^2\rho_g(q_g/q_l)] = 12(q_l/q_g)/(N_{Weg})_{32} \\ &= 12(q_l/q_g)(\rho_l/\rho_g)/(N_{Wep})_{32} = 12(w_l/w_g)/(N_{Wep})_{32} \ , \qquad (26)\end{aligned}$$

which differs from Equation 25 only by the loading ratio (w_l/w_g).

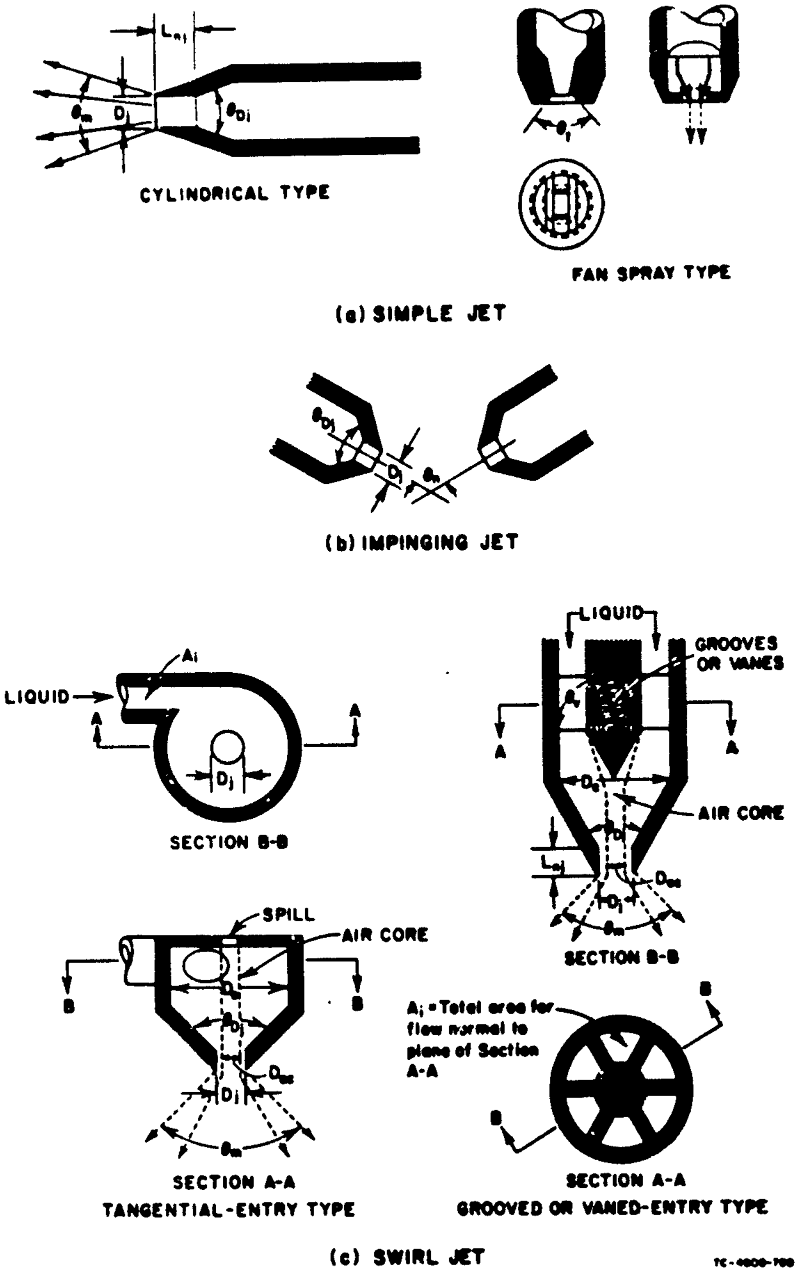


FIG. 1 TYPES OF HYDRAULIC ATOMIZING NOZZLES
(a) Simple Jet
(b) Impinging Jet
(c) Swirl Jet

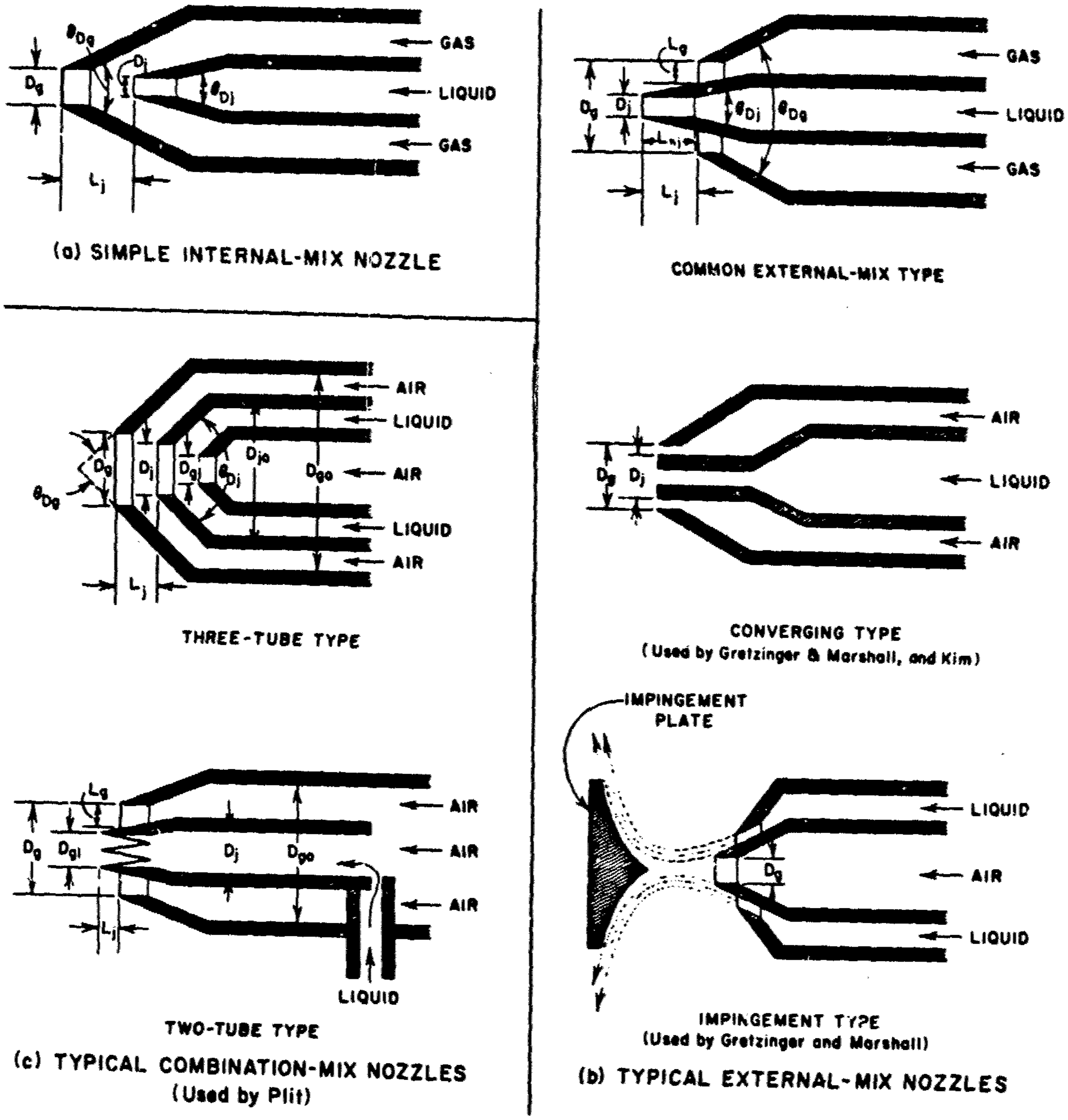
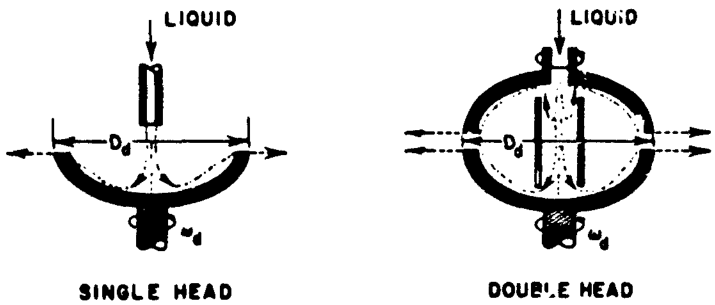
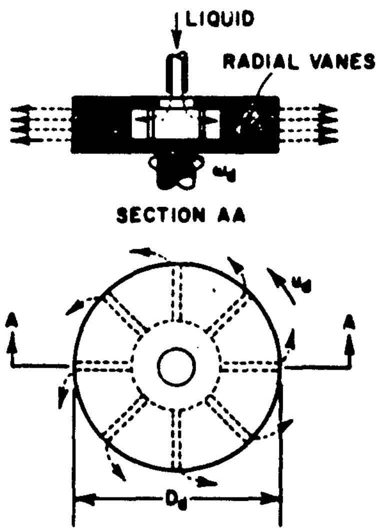


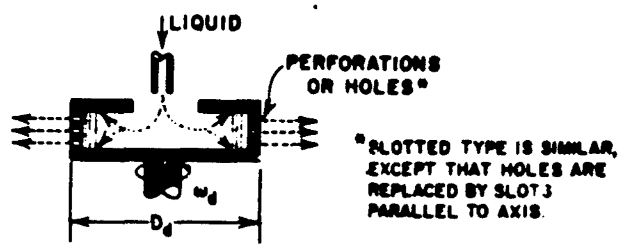
FIG. 2 TYPES OF PNEUMATIC ATOMIZING NOZZLES
(a) Simple Internal-Mix Nozzle
(b) Typical External-Mix Nozzles
(c) Typical Combination-Mix Nozzles



(a) SIMPLE FILM TYPE
(Dish or saucer illustrated)



(b) VANED FILM TYPE



(c) PERFORATED HEAD TYPE

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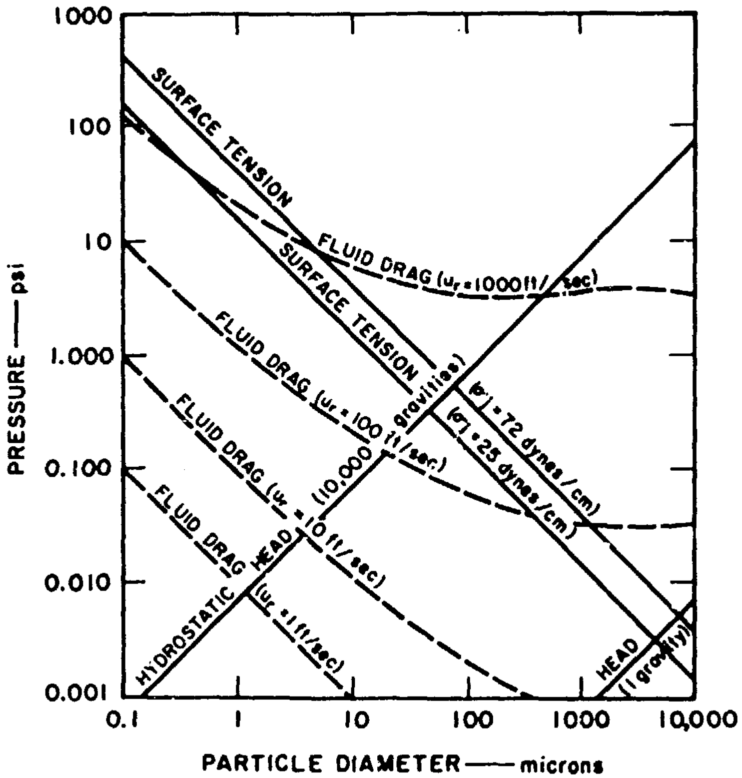
FIG. 3 TYPES OF ROTARY (SPINNING DISK) ATOMIZERS
(a) Simple Film Type
(b) Vaned Film Type
(c) Perforated Head Type



MECHANISM OR PRESSURE SOURCE	MAGNITUDE OF PRESSURE DUE TO SOURCE	ASSUMED VALUES FOR PLOT
SURFACE TENSION	$4\sigma_j/D_p$ internal drop pressure	σ_j = 25 AND 72 dynes / cm
HYDROSTATIC HEAD (gravity or centrifugal)	$a\rho_j D_p/2$ (at drop midpoint)	ρ_j = 1 g/cu cm a = 1 gravity and 10^4 gravities
FLUID DRAG (pressure and shear)	$C_D \rho_g u_r^2/2$ $C_D = \psi(N_{Repg})$ $N_{Repg} < 0.2$: $C_D = 24/N_{Repg}$ $N_{Repg} > 1000$: $C_D \approx 0.44$ (for spheres)	ρ_g = 0.001185 g/cu cm, μ_g = 0.0184 cp } AIR AT 25°C 1 atm u_r = 1, 10, 100, and 1,000 ft/sec (slip-flow, compressibility, and droplet deformation effects neglected)

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FIG. 4 PRESSURES EXERTED ON DROPS BY VARIOUS MECHANISMS

Table I

SUMMARY OF ATOMIZING TECHNIQ

GENERAL TECHNIQUE (Alternate Names)	TYPE	VARIATIONS OR EXAMPLES	
Hydraulic (pressure)	Simple (axial) jets	Stationary Rotating or moving Fan Spray	Fluid pressure is converted into fluid velocity by passage of flu jet instability arising from relative velocity of liquid to the a jet, the relative velocity is increased by the physical motion of noncircular orifice and/or orifice feed chamber.
	Impinging jets	Impinging liquid jets Impingement of liquid jet on solid surface	Collision of two simple jets or impingement of a simple jet on a atomizer may produce a bi-modal size distribution.
	Swirl nozzle (centrifugal)	Tangential entry Vaned or grooved entry	A circular orifice is preceded by a chamber in which the liquid i grooves or vanes. A hollow conical sheet is produced. The non-cl
Pneumatic (two-phase or two fluid)	Internal mix		The high relative velocity between gas and liquid is achieved by mixed prior to the gas expansion through the nozzle in the intern atomization is possible at relatively low pressure levels.
	External mix		
	Combination mix		
Rotary (spinning disk or cup)	Film (liquid flows parallel to disk surface)	Simple (flat, dished, cupped, or saucer; single or double) Vaned	Liquid is introduced at the center of a rotating disk and flows o disk as a thin sheet. In the head type, a liquid leaves as a lig ally a hydraulic technique in which the pump and nozzle are combi tively free from plugging problems. Fineness of atomization is l techniques, such limits can be avoided by using pumps with staged
	Head or basket (liquid flows normal to disk surface)	Perforated Slotted	
Vibrational	Mechanical	Vibrating tube Vibrating reed	A liquid is fed to or caused to flow over a surface which vibrat Uniform drops may be produced at low feed rates. This technique
	Sonic	Compressed air siren Hartman whistle	
	Ultrasonic	Solid-state oscillators	
Explosive			A bulk liquid is exposed to expanding gas products from a detona sition of the liquid may occur because of the high temperature.
Electrostatic	Low intensity	Atomization is the result of Rayleigh instability, in which presence of charge in surface counter-acts surface tension	The liquid jet or film is exposed to an electric field. The for nique is relatively undeveloped. Much of present day research i spray painting probably uses an electrostatic field for depositi
	High intensity	Atomization claimed to be the result of stress sufficient to overcome tensile strength (or chemical bonds) of liquid	
Gravitational	Pendant or hanging drop	Quasi-static emission of a drop from a wetted surface, as from the end of a burette (discontinuous surface) or from the underside of a horizontal surfaced (continuous surface)	These are classic examples of common atomization processes in na
	Dripping drop	Periodic emission of drops from the bottom side of a surface to which a liquid is fed continuously as in dripping of water from leaves	
	Falling or splashing drop (or object)	Satellite drops generated due to impact of object on a liquid surface	
Film bursting	Bursting bubble		Generation of droplets results from the sudden failure of a stre
	Flashing fluid (superheated)		

Table I

MMARY OF ATOMIZING TECHNIQUES

DESCRIPTION AND CHARACTERISTICS
id velocity by passage of fluid through a plain orifice or nozzle to produce a rod-like stream. Atomization occurs as a result of a e velocity of liquid to the ambient gas. This technique requires high liquid pressures for fine atomization. In a rotating or moving sed by the physical motion of the atomizing nozzle (e.g., a spray nozzle mounted on an airplane). Fan sprays are produced by use of a ped chamber.
ngement of a simple jet on a deflecting surface produces a sheet of liquid which subsequently breaks up into drops. This type of distribution.
hamber in which the liquid is given a tangential velocity component either by a tangential liquid entry or by a series of inclined ent is produced. The non-clog feature of the tangential type results from the ability to use larger apertures for a given capacity.
s and liquid is achieved by acceleration of the gas to high velocity rather than acceleration of the liquid. Gas and liquid are ugh the nozzle in the internal-mix type and after the gas expansion in the external-mix type. Power consumption is high but fine low pressure levels.
a rotating disk and flows outward by action of the centrifugal force field. In the film type, a liquid leaves the outer edge of the pe, a liquid leaves as a ligament or it may form a series of sheets through the peripheral holes or slits in the rim. This is basic- he pump and nozzle are combined as an integral unit. The film type is capable of producing uniform drops at low capacity and is rela- Fineness of atomization is limited because of rotational speed limits imposed by the strength of structural materials. In hydraulic d by using pumps with staged impellers.
over a surface which vibrates at a prescribed frequency and amplitude. The droplet size is primarily a function of the frequency. feed rates. This technique is relatively undeveloped.
gas products from a detonating system. This is probably a special case or extension of the pneumatic technique. Chemical decompo- e of the high temperature. Although atomization may be fine, coarse debris may also be present.
an electric field. The force on the liquid may be due to either free charges in the surface or to liquid polarization. This tech- h of present day research is aimed at rocket propulsion by charged droplets generated in high vacuum. Conventional electrostatic rostatic field for deposition of drops on surface rather than in generation of the drops themselves.
tomization processes in nature. They are, however, normally limited to either low-rate or coarse atomization.
e sudden failure of a stressed film of liquid. This is a low-capacity atomizing technique.

Table II

RANGE OF EXPERIMENTAL CONDITIONS

INVESTIGATOR	ATOMIZER DETAILS: Type	Diameters, cm: D_j or D_d	Diameters, cm: D_g	Other Details	LIQUID PROPERTIES: Chemical Composition	Density ρ_j g/cu cm	Viscosity μ_j centipoise	Surface Tension σ_j dynes/cm	GAS PROPERTIES*: Composition	Pressure atm. abs.	Te
Dombrowski and Hooper (1962)	Impinging jets	0.053		2 jets at 110°	Water Ethyl alcohol 48 wt. % glycerin in water	1.0 0.79 1.12	1.0 1.1 5.5	73 24 68	air	0.06-20, mostly 1-20	
Dombrowski and Hooper (1964)	Impinging jets	0.05		2 laminar jets at 50 to 140° 2 turbulent jets at 50 to 140°	Water (0.5% nigrosine dye)				air	1	
Fraser and Eisenklam (1956)	Fan jet			exit angle varied from 108° to 120°	Water				air	1	
Fraser, Eisenklam and Dombrowski (1957)	Fan jet				Dyed liquid	0.8-1		28-73	air	1	
Fraser, Dombrowski and Routley (1963)	Spinning disk and pneumatic combined	10		air jet 0.2 in. out from cup lip in form of annular ring	oils (three types)	0.81-0.83	4-137 (mostly 37)	29-35	air (air)	1 (1-1.2)	(
Friedman, Gluckert and Marshall (1952)	Spinning disk	2.5-10		used 13 different disks; L_w ranged from 0.8" to 49 cm	A B C D (probably molten salt)	1.00 1.37 1.42 1.41	1.0 1200. 9040. 1.6	72 75 76 100	air	1	ro
Gretzinger and Marshall (1961)	Pneumatic-convergent	0.14-0.55	0.37-0.71	3 nozzle; for each A_g = 0.080 cm^2; D_{g^e} = 0.33 cm; air on outside	water (with dye)	1.0	1.0	72	air (air)	1 (2-8)	(
	Pneumatic-impingement		0.24-0.32	3 nozzles; air in center							
Harmon (1955)	Stationary jet	used data of Lee (1932), Lee and Spencer (1933) and Kuehn (1925)			alcohol gasoline diesel oil kerosene						
Hasson and Mizrahi (1961)	Fan jet	0.034-0.134 (D_{je})		A_j = 0.0009-0.014 sq cm; 118° spray angle	waxes (90 to 125°C) water (12 to 15°C) 28% $CaCl_2$ in water (25°C) di-ethylphthalate (20°C) kerosene (12°C)	0.75-0.85 1.0 1.27 1.12 0.8	3-21 1.1-1.2 2.7 12.6 2	25-31 74 85 38 28	air	1	
Il'yashenko and Talantov (1964)	Swirl jet				fuel oil				air (?)	1(?)	
Joyce (1949)(1953)	Swirl jet				fuel oil		2-16		air	1	
Kim (1959)	Pneumatic	0.14-0.56	0.3-0.7	Mostly concentric with air on outside; D_{ge} = 0.17-0.67 cm	mixtures of wax with polyethylene	0.8-1	1-50	30-50	air (air)	1 (1-6)	
Knight (1955)	Swirl jet	used data of Needham (1946) and Lubbock and Bowen (1948)			fuel oil	0.8 (?)	1.8 (?)		air (?)	1 (?)	
Kruse, Hess, and Ludvik (1949)	Stationary and moving fan jet			No 8002 "Teejet" (Chicago Spraying Systems Co.)	20% DDT in Velsicol NR-70 20% DDT in Sovacide 544B water	1.08 1.04 1.00	9 5.25 1	34 42 72	air	1	
Kurabayasi (1960)(1961)	Rotating simple jet	0.04-0.12			glycerin/water (0 to 60 wt %) ethyl alcohol/water (0 to 30 wt %)	1.0-1.16 1	1-13 1	74-65 35-54	air	1	
Kuznetsov and Talaf (1958)	Impinging jet	0.08-0.34		jet impinges axially on deflecting cone	water	1	1	72	air	1	
Longwell (1943)	Swirl jet				fuel oil						
Mayer (1961)	Theoretical	used data of Weiss and Worsham (1958)									
McIrvine (1957)	Swirl jet	used extensive data from literature; also ran some tests on 22 chambers with 5 orifice diameters ranging from D_j = 0.09-0.5 cm			sucrose/water solutions (with 3.5% nigrosine dye)	1-1.3	0.9-105.	60-67	air	1	
Merrington and Richardson (1947)	Stationary jets Moving jets	0.08-0.8 1.0-1.8			11 liquids	1-1.77	0.5-1260	25-73	air	1	
Mugele (1960)	All types	used data of many investigators									
Nelson and Stevens (1961)	Swirl jet	0.035-0.21		Type SL nozzles (Spraying Systems Co.); spray angle 52°-91°	cyclohexane, n-octyl alcohol, carbon tetrachloride, water, nitrobenzene, aniline, tetrabromethane				nitrogen helium	1 1	

Table II

XPERIMENTAL CONDITIONS USED BY INVESTIGATORS

GAS PROPERTIES*			OPERATING CONDITIONS						DROP DIAMETER			REMARKS
Composition	Pressure atm. abs.	Temperature °C	Liquid Rate cu cm/sec	Liquid Pressure Δp psi	Disk Rotational Speed ω_d rpm	Liquid Velocity at Nozzle Discharge u_j or u_d cm/sec	Relative Gas-Liquid Velocity u_r cm/sec	Liquid-to-Gas Loading g liquid/g gas	Type	Magnitude Microns	Method of Measurement	
air	0.06-20, mostly 1-20	18		25-120		1600-4200			D_{32}	120-180	micro-second flash photographs	C_q = 0.91; "FN" = 1.17
air	1	room				730-1950			D_{32}	100-550	micro-second flash photograph	Nozzles were 20 cm long (L_j); jet made turbulent by inserting wires into flared entry
air	1	room		25-100		1490-3540			D_{32}	84-280	drops collected in oil, photographed, counted (?)	"FN" varied from 0.35 to 2.17 (C_q from 0.60 to 0.95)
air	1	room		45-105					D_{32}			"FN" varied from 0.5 to 8
air (air)	1 (1-1.2)	room (room)	40-160		1500-5000	730-3300	2950-20,000 (mostly 3000-10,000)	0.26-6	D_{32}	20-300	light absorption	
air	1	room (?)	4-510		860-18,000	640-9600			D_{32} D_{pmax}	69-776 114-2000	photographed petrolatum or magnesium oxide-coated slides	Γ_j/μ_j ranged from 343 to 2780 for liquid A; Γ_j ranged from 0.4 to 22 (g)/(sec)(cm)
air (air)	1 (2-8)	room (room)	0.5-5				~30,000	0.06-1	D_{mv}	5-30	counting and measuring quantity of dye residue in collected drops	
air	1	room		20-140		1400-4600			D_{32}	40-300	microscopic count of slide exposed to spray for liquids; sieving with dry ice for waxes; microscupic count of slide covered with oil and of stains on absorbent paper for water	C_q = 0.8-0.94; "FN" = 0.2-3.8
air (?)	1(?)											
air	1	room	5-40	12-125					D_{32}	50-200		
air (air)	1 (1-6)	room (room)	0.1-16				7500-30,000	0.02-17	D_{mv}	6-350	microscopic count and sieving	
air (?)	1 (?)		2-200 (?)	50-1000 (?)								
air	1	room		20-100			0-8000		D_{32}	70-300	deposition on slides and microscopic count (water drops required carbon coated slides)	
air	1	room	0.1-6				400-10,000		D_{32}	60-2000	collected on oil-covered slide, photographed, and counted	
air	1	room				1000-5000			D_{xx}	200-500 (?)	not specified	
air	1	room		30-300					D_{32}	20-300	collected on slides, covered with solvent, photographed, and counted electronically	Data were primarily on nozzle flow characteristics and spray pattern. Limited drop size data were not adequately correlated.
air	1	room		100-680			500-10,000		D_{mv}	80-2000	collected on blotting paper and size of dye stain measured	Aircraft speeds up to 6000 cm/sec
rogen um	1 1	less than 25°C		100-1500					D_{av}	40-100	drops collected in liquid nitrogen and sieved	

Table II (Concluded)

RANGE OF EXPERIMENTAL CONDITIONS USED BY I

INVESTIGATOR	ATOMIZER DETAILS				LIQUID PROPERTIES				GAS PROPERTIES*			
	Type	Diameters, cm		Other Details	Chemical Composition	Density ρ_j g/cu cm	Viscosity μ_j Centipoise	Surface Tension σ_j dynes/cm	Composition	Pressure atm. abs.	Temperature °C	Li R cu
		D_j or D_d	D_g									
Nukiyama and Tanasawa (1939)	Pneumatic	0.02-0.3	0.2-0.5	concentric, internal mix	solutions of methanol, ethanol, and glycerin in water	1.0-1.2	1-25	34-73	air (air)		room (room)	
Panasenkov (1951)	Stationary jet	0.034-0.12		cylindrical nozzle, four diameters long	water, starch solution, machine oil		1-120		air	1	room	
Peskin and Lawler (1962)	Spinning disk	theoretical analysis										
Plit (1962)	Pneumatic	0.7-2.0	1.2-2.5	internal and external mix nozzles	water; monoethanolamine; potassium carbonate solutions				air (air)	1 (1-1.03)?	room (room)	
Popov (1956)	Simple jet	0.06-0.10			water carbon tetrachloride methanol	1.0 1.0 0.63	1.0 1.6 0.79	73 26 23	air (μ_g = 0.018 cp) acetylene (μ_g = 0.010 cp) neon (μ_g = 0.031 cp)	1 1 1	room room room	
Putnam, et al (1957)	All	used data of many investigators										
Radcliffe (1954)(1955)	Swirl jet	0.05-0.18			carbon tetrachloride, gasoline, kerosene, kerosene and oil solutions	0.75-1.6	0.5-25		air	1	room	
Tanasawa and Kobayasi (1955)	Swirl jet	0.05-0.42			glycerine/water solutions gasoline kerosene heavy oil	 0.750 0.802 0.895	1-42 0.35 2.84 3.1 (?)	51-75 23 30 31	air	1	room	0
Tanasawa, Sasaki, and Nagai (1957)	Impinging jet	0.04-0.10		hypodermic tubing pointed at each other	ethyl alcohol/water solutions glycerin/water solutions kerosine kerosine/lube oil (62.5%/37.5%)	0.88-1 0.884 0.870	1.2-2.6 1.2-31 6.3 21.	28-73 63-73 29 30	air	1	room	1
Tanasawa and Toyoda (1956)	Stationary jet	0.027		long cylindrical throat–3 hole Bosch type; also made some measurements, with other nozzles such as pintle, throttle, impingement, and swirl	waxes (50-100°C) gasoline (30°C) kerosine (30°C) heavy oil (30°C) ethanol (30°C)	0.76-0.90 0.75 0.84 0.93 0.78	1.4-25 0.53 1.75 70. 1.00	22-30 21 24 32 21	air	1	room	
Tanasawa and Toyoda (1955)	Stationary jet	0.025-0.105 (used 0.025-0.067 only for drop size)		long cylindrical throat	water, glycerin, alcohol, oils (used only water for drop size)				air	1	room	
Tate and Marshall (1953)	Swirl jet	0.034-0.10		Spraying Systems Co. nozzles	water, water/glucose solutions (dyed with 2.5% nigrosine)			62.5	air	1	room	
Turner and Moulton (1953)	Swirl jet	0.07-0.20		Spraying Systems Co. nozzles 1/4 *LN* and 1/8 *A*	beta naphthol, benzoic acid (131 to 182°C)	1.04-1.08	0.8-2.0	27-37	air	1	room	
Walton and Prewett (1949)	Spinning disk	2-8			water, methyl salicylate, dibutyl phthalate, mercury, glycerin, o-dichlorbenzene, ethylene dibromide, dekalin, tricresyl phosphate	0.9-13.6	1-1500	31-465	air	1	room	
Weiss and Worsham (1959)	Stationary jet into flowing gas	0.12-0.48	15 (air duct diam.)	cylindrical tubes	Acrawax C (m.p. 284-290°F)	0.806-0.828	3-11	18-22	air	1-5	room	
Wetzel and Marshall (1954)	Pneumatic	0.034-0.071	3.8-6.4 (venturi throat)	cylindrical liquid feed jet directed along axis of venturi throat cocurrent with air; 25°C incl. angle converging and diverging	wax, with dye (m.p. 190°F) alloy (m.p. 203°F)	0.83 9.8	8.7 5.5 (?)	29.6 470	air (air)	0.8-1.4? (1-1.4)?	room (room)	
Wigg (1960)	Pneumatic	various atomizers and data of others			wax [data of Clare and Radcliffe (1954) and Wood (1954)], water, iso-octane		2.5-33	23-26	air (air)	1 (1-3)	room (room)	

* Gas into which spray discharges; in case of pneumatic atomization, type and upstream pressure is given in parenthesis.

† 1 gal/hr =

Table II (Concluded)

F EXPERIMENTAL CONDITIONS USED BY INVESTIGATORS

	GAS PROPERTIES*			OPERATING CONDITIONS						DROP DIAMETER			REMARKS
ace ion /cm	Composition	Pressure atm. abs.	Temperature °C	Liquid Rate† cu cm/sec	Liquid Pressure Δp psi	Disk Rotational Speed ω_d rpm	Liquid Velocity at Nozzle Discharge u_j or u_d cm/sec	Relative Gas-Liquid Velocity u_r cm/sec	Liquid-to-Gas Loading g liquid/g gas	Type	Magnitude Microns	Method of Measurement	
3	air (air)		room (room)					6000-33,000	0.08-2	D_{32}	10-90		
	air	1	room				100-2300			D_{30}	500-3000	allowed drops to impinge on plate, weighed entire mass and counted number of drops	N_{Rejj} from 500 to 8,000
	air (air)	1 (1-1.03)?	room (room)					2500-7500	0.1-10	D_{32}	10-1000	measured light absorption from known ratio of liquid to gas flow calculated diameter of drops	
	air (μ_g = 0.018 cp) acetylene (μ_g = 0.010 cp) neon (μ_g = 0.031 cp)	1 1 1	room room room				1600-6300			D_{xx} (probably D_{10} or D_{mn})	100-500	microsecond flash photograph	N_{Rejj} from 41,800 to 66,000
	air	1	room		5-1000					Needham used: D_j = 0.1 cm; 6-125 psi; "FN" = 0.5-4.2 Joyce used: D_j = 0.09-0.19 cm			Experiments covered nozzle flow pattern and capacity only; quotes Needham (1946) and Joyce (1949) for drop size data
5	air	1	room	0.5-89	2-4500					D_{32}	25-250	spray collected in concentric rings and weighed; sample photographed, counted, and integrated	N_{Rejj} varied from 200-40,000
	air	1	room	1.5-41			?00-5000			D_{32}	70-320	counting of photomicrographs	N_{Rejj} varied from 100-20,000
	air	1	room		150-6300		2900-22,000			D_{32}	30-550	(1) collected drops under liquid, photographed and counted (2) solidified waxes, sieved (counted for sizes under 50μ)	Intermittent flow (usually 500 rpm)
	air	1	room		750-4500		200-12,600			D_{32}	70-620	counting of photomicrographs	Also give data on pendant and dripping drop
	air	1	room	4-22	60-950					D_{32}	20-200	collected drops in Stoddard solvent, photographed, counted	
	air	1	room	1.8-28.	27-127					D_{lmv}	70-230	solidified drops collected, sampled, counted and measured microscopically	
5	air	1	room	0.04-2.8		300-100,000	52-15,500			D_{xx}	12-3000	drops collected on magnesium-oxide coated slides and counted	
	air	1-5	room	6-190			120-3000	6000-30,000		D_{mv}	19-118	solidified drops collected and analyzed in Micromerigraph; checked by microscopic count	
	air (air)	0.8-1.4? (1-1.4)?	room (room)	1.1-4.7 0.74			640-1900 460	6000-25,000	0.002-0.05	D_{mv}	25-150	solidified drops collected, photographed, counted	
	air (air)	1 (1-3)	room (room)	10-120				9000-34,000	0.15-20.	D_{mv}	10-200		

† 1 gal/hr = 1.05 cu cm/sec

Table III

SUMMARY OF DATA ON HYDRAULIC (PRESSURE)

A. Simple Jet

AUTHOR	UNITS REQUIRED	EXPANDED RELATIONSHIP FOR AVERAGE DIAMETER	CONVERSION TO GENERALIZED FORMAT: $(D_{xx}/D_j) = k$ (Note: For any axial-jet nozzle stationary with atmosphere, u_j and u_r are identical) — Type Diameter Ratio (D_{xx}/D_j)	Controlling Variables Assumed	k
Fraser and Eisenklam (1956)	cgs	$D_{32} = \frac{2.07\Delta p^{0.055} D_{je}^{1.96}\sigma_j^{0.25}}{\theta_j^{0.37} q_j^{0.61}\rho_j^{0.425}} = \frac{2.31 N_{vj}^{0.055} D_{je}^{0.74}\sigma_j^{0.25}}{\theta_f^{0.37} u_j^{0.5}\rho_j^{0.37}}$	D_{32}/D_j	(D_j, u_r) with fixed geometry	$\frac{2.31 N_{vj}^{0.055}\sigma_j^{0.01}(D_{je}/D_j}{\theta_f^{0.37}\rho_j^{0.11}\mu_j^{0.02}}$
				(u_r, σ_j)	$\frac{2.31 N_{vj}^{0.055}(D_{je}/D_j)^{0.}}{\theta_f^{0.37} D_{je}^{0.01}\rho_j^{0.12}}$
Fraser, Eisenklam, and Dombrowski (1957)	cgs	$D_{32} = \frac{4.39 q_j^{1/3}\sigma_j^{1/3}}{\theta_f^{1/3}\Delta p^{1/2}} = \frac{5.73 D_{je}^{2/3}\sigma_j^{1/3}}{\theta_f^{1/3} N_{vj}^{1/2} u_j^{2/3}\rho_j^{1/2}}$	D_{32}/D_j	any except ρ_j with fixed geometry	$\frac{5.73(D_{je}/D_j)^{2/3}}{\theta_f^{1/3} N_{vj}^{1/2}\rho_j^{1/6}}$
Harmon (1955)	consistent	$D_{32} = \frac{3330 D_j^{0.3}\mu_j^{0.07}\mu_g^{0.78}}{u_j^{0.55}\rho_j^{0.648}\rho_g^{0.052}\sigma_j^{0.15}}$	D_{32}/D_j	(D_j, u_r)	$3330\left(\frac{\mu_g}{\mu_j}\right)^{0.78}\left(\frac{\rho_j}{\rho_g}\right)$
Hasson and Mizrahi (1961)	cgs	$D_{32} = \frac{C_{HM} D_{je}^{2/3}\mu_j^{1/6}\sigma_j^{1/3}}{[\sin(\theta_f/2)]^{1/3} u_j^{2/3}\rho_j^{1/6}}$	D_{32}/D_j	(D_j, u_r) with fixed geometry	$\frac{C_{HM}(\rho_j\mu_j)^{1/6}(D_{je}/D_j)^{2/}}{[\sin(\theta_f/2)]^{1/3}}$
		where C_{HM} = 5.2 for molten wax; 7.5 for normal liquids			
Kruse, Hess, and Ludvik (1949)	cgs	$D_{32} = \frac{19.8\mu_j^{1.06}\sigma_j^{1.06}}{u_j^{0.80} u_r^{0.26}\rho_j^{1.06}}$	D_{32}/D_j	(D_j, u_r) with fixed velocity ratio (u_r/u_j)	$19.8\mu_j^{0.12}\sigma_j(u_r/u_j)^{0.80}$
				(u_r, μ_j) with fixed velocity ratio (u_r/u_j)	$19.8 D_j^{0.06}\sigma_j^{1.06}(u_r/u_j)$
Kurabayasi (1961)	cgs	$D_{32} = \frac{86.2\sigma_j^{0.25}}{u_r^{1.15}\rho_j^{0.25}}$	D_{32}/D_j	(u_r, σ_j)	$86.2(\rho_j/\mu_j)^{0.65}/D_j^{0.1}$
Mayer (1961)	consistent	$D_{xx} = \frac{C_M\mu_j^{2/3}\sigma_j^{1/3}}{u_r^{4/3}\rho_j^{1/3}\rho_g^{2/3}}$	D_{xx}/D_j	(any except ρ_j)	$C_M(\rho_j/\rho_g)^{2/3}$
		where $C_M = 18\pi(2)^{1/3} k_M = 21.3$ for $k_M = 0.3$			
Merrington and Richardson (1947)	cgs	$D_{mv} = \frac{500 D_j^{0}\mu_j^{0.2}}{{}_r\rho_j^{0.2}}$	D_{mv}/D_j	(D_j, u_r)	$500(\rho_j/\mu_j)^{0.8}$
				(u_r, μ_j)	$500(\rho_j/\sigma_j D_j)^{0.4}$
Mugele (1960)	consistent	$D_{32} = \frac{5.0 D_j^{0.65}\mu_j^{0.15}\sigma_j^{0.20}}{u_r^{0.55}\rho_j^{0.35}}$	D_{32}/D_j	any	5.0

Table III

N HYDRAULIC (PRESSURE) ATOMIZATION

A. Simple Jet

FORMAT: $(D_{xx}/D_j) = k/N^{\alpha}_{Rejr}N^{\beta}_{Cajr} = k/N^{\alpha-\beta}_{Rejr}N^{\beta}_{Wejr}$ nozzle stationary with respect to the ambient u_r are identical)			COMPARISON OF PARTICLE SIZE PREDICTIONS AT STANDARD REFERENCE CONDITIONS (SEE TABLE VI)			REMARKS
k	α	β	Additional Specifications for Reference Conditions	Average Diameter Calculated at Standard Reference Conditions, D_{xx}, Microns: u_r = 1,000 cm/sec	Average Diameter Calculated at Standard Reference Conditions, D_{xx}, Microns: u_r = 10,000 cm/sec	
$\dfrac{2.31N_{vj}^{0.055}\sigma_j^{0.01}(D_{je}/D_j)^{0.74}}{\theta_f^{0.37}\rho_j^{0.11}\mu_j^{0.02}}$	0.26	0.24	$\theta_f = 90° = \pi/2$ radians $N_{vj} = 1$ $(D_{je}/D_j) = 1$	355	112	Fan spray nozzle
$\dfrac{2.31N_{vj}^{0.055}(D_{je}/D_j)^{0.74}}{\theta_f^{0.37}D_{je}^{0.01}\rho_j^{0.12}}$	0.25	0.25				
$\dfrac{5.73(D_{je}/D_j)^{2/3}}{\theta_f^{1/3}N_{vj}^{1/2}\rho_j^{1/6}}$	1/3	1/3	$\theta_f = 90° = \pi/2$ radians $N_{vj} = 1$ $(D_{je}/D_j) = 1$	492	106	Fan spray nozzle
$3330\left(\dfrac{\mu_g}{\mu_j}\right)^{0.78}\left(\dfrac{\rho_j}{\rho_g}\right)^{0.052}$	0.7	-0.15		147	41.6	Stationary jet
$\dfrac{C_{HM}(\rho_j\mu_j)^{1/6}(D_{je}/D_j)^{2/3}}{[\sin(\theta_f/2)]^{1/3}}$	1/3	1/3	$\theta_f = 90°$ $(D_{je}/D_j) = 1$	272 (wax)	58.6 (wax)	Fan spray ($\theta_f = 118°$)
				390 (normal liquids)	84.0 (normal liquids)	
$19.8\mu_j^{0.12}\sigma_j(u_r/u_j)^{0.80}/\rho_j^{0.06}$	1.00	0.06	$(u_r/u_j) = 1$	131	11.4	Fan spray, stationary and moving jets; insecticide spreading (Chi-Spraying Systems, "Veejet" nozzle).
$19.8D_j^{0.06}\sigma_j^{1.06}(u_r/u_j)^{0.80}$	1.06	0.00				
$86.2(\rho_j/\mu_j)^{0.65}/D_j^{0.10}$	0.90	0.25		970	68.8	Moving (rotating) jets.
$C_M(\rho_j/\rho_g)^{2/3}$	1	1/3		459	21.3	Theoretical for gas flow over a liquid surface; k_M = 0.3 from experimental spot checks.
$500(\rho_j/\mu_j)^{0.8}$	1	0		1990	199	Moving and stationary jets.
$500(\rho_j/\sigma_j D_j)^{0.4}$	0.6	0.4				
5.0	0.35	0.20		315	89	Moving and stationary jets.

Table III

SUMMARY OF DATA ON HYDRAULIC (PRESSURE) ATOM

A. Simple Jet

AUTHOR	UNITS REQUIRED	EXPANDED RELATIONSHIP FOR AVERAGE DIAMETER	CONVERSION TO GENERALIZED FORMAT: $(D_{xx}/D_j) = k$ (Note: For any axial-jet nozzle stationary wit atmosphere, u_j and u_r are identical)		
			Type Diameter Ratio (D_{xx}/D_j)	Controlling Variables Assumed	k
Panasenkov (1951)	consistent	$D_{30} = \frac{6D_j^{0.85}\mu_j^{0.15}}{u_j^{0.15}\rho_j^{0.15}}$	D_{30}/D_j	any	6
Popov (1956)	consistent	$D_{xx} = \frac{0.00324D_j^{1.15}\rho_j^{0.55}\sigma_j^{1.15}}{u_r\rho_g^{0.40}\mu_j^{1.22}\mu_g^{0.08}}$	(D_{xx}/D_j)	(D_j,u_r); (D_j,σ_j); or (u_r,σ_j)	$0.00324(\mu_j/\mu_g)^{0.08}(\rho_j/$
		The author does not define his mean diameter. It can be inferred that he used either a number mea He presented all his data in the form of graphs. While the above expanded relationship fits his d report it. His data are probably for a simple hydraulic converging nozzle although he gives no de plots of particle size distribution some of which could not be reconciled with his other atomizati showing the relative effect of gas viscosity and gas density are reasonably direct but the data fr D_j, ρ_j, μ_j, and σ_j are taken are subject to the irreconcilable particle size data.			
Putnam *et al.* (1957) (Pilcher and Miesse)		$D_{xx} = \psi\left[\frac{D_j^{0.5}\mu_j^{0.2}}{\Delta p^{0.4}\rho_j^{0.2}}\right] = \psi_1\left[\frac{D_j^{0.5}\mu_j^{0.2}}{N_{vj}^{0.4}u_j^{0.8}\rho_j^{0.6}}\right]$			
Tanasawa and Toyoda (1955)(1956)	consistent	$D_{32} = \frac{C_{TT}g_L^{0.25}D_j\sigma_j^{0.25}k_{\mu j}}{u_j\rho_g^{0.25}}$ where C_{TT} = dimensionless constant = 47 for steady flow, 70.5 for intermittent flow; $k_{\mu j} = \left[1+3.31\left(\frac{\mu_j^2}{D_j\rho_j\sigma_j}\right)^{0.5}\right] = \left[1+3.31N_{Ohjj}^{0.5}\right]$	D_{32}/D_j	(D_j,u_r)	$C_{TT}(g_L u_j^4/\rho_g\sigma_j^3)^{0.25}k_{\mu j}$
				(D_j,σ_j)	$C_{TT}(g_L\mu_j/\rho_g u_r^3)^{0.25}k_{\mu}$
				(u_r,σ_j)	$C_{TT}(g_L\rho_j^3D_j^3/\rho_g\mu_j^2)^{0.2}$
Tanasawa and Kobayasi (1955)	consistent	$D_{32} = \frac{4.74D_j^{0.75}\sigma_j^{0.25}k_{\mu j}}{\Delta p^{1/4}} = \frac{5.64D_j^{0.75}\sigma_j^{0.25}k_{\mu j}}{N_{vj}^{0.25}u_j^{0.5}\rho_j^{0.25}}$ where $k_{\mu j} = \left[1+15.56\left(\frac{\mu_j^2}{D_j\rho_j\sigma_j}\right)^{1.5}\right] = \left[1+15.56N_{Ohjj}^{1.5}\right]$	D_{32}/D_j	(any except μ_j)	$5.64k_{\mu j}/N_{vj}^{0.25}$
Weiss and Worsham (1959)	consistent	$D_{av} = \frac{597D_j^{1/6}u_j^{1/12}\mu_j^{1/3}\mu_g^{1/12}\sigma_j^{5/12}k_{\rho g}}{u_r^{4/3}\rho_j^{5/6}}$ where $k_{\rho g} = [1+(1/N_p)]$ or $[1+(\rho_j/1000\rho_g)]$ for range of conditions covered by the authors	D_{av}/D_j	(D_j,u_r) or (ρ_j,μ_j)	$597(u_j\mu_g/\sigma_j)^{1/12}k_{\rho g}$
				(ρ_j,σ_j); or (u_r,σ_j with constant u_j/u_r)	$597\left(\frac{\mu_g}{\mu_j}\right)^{1/12}\left(\frac{u_j}{u_r}\right)^{1/12}k_{\rho g}$
				(μ_j,σ_j)	$597\left(\frac{\mu_g}{D_j\rho_j u_r}\right)^{1/12}\left(\frac{u_j}{u_r}\right)^{1/1}$
				(u_r,σ_j)	$597\left(\frac{D_j\rho_j u_j}{\mu_j}\right)^{1/12}\left(\frac{\mu_g}{\mu_j}\right)^{1}$

Table III

ULIC (PRESSURE) ATOMIZATION (Continued)

A. Simple Jet

FORMAT: $(D_{xx}/D_j) = k/N^{\alpha}_{Rejr} N^{\beta}_{Cajr} = k/N^{\alpha-\beta}_{Rejr} N^{\beta}_{Wejr}$ nozzle stationary with respect to the ambient u_r are identical)			COMPARISON OF PARTICLE SIZE PREDICTIONS AT STANDARD REFERENCE CONDITIONS (SEE TABLE VI)			REMARKS
k	α	β	Additional Specifications for Reference Conditions	Average Diameter Calculated at Standard Reference Conditions, D_{xx}, Microns: u_r = 1,000 cm/sec	u_r = 10,000 cm/sec	
6	0.15	0		1510	1068	Stationary jet.
$.00324(\mu_j/\mu_g)^{0.08}(\rho_j/\rho_g)^{0.40}$	-0.15	1.15		4220	422	
d either a number mean (D_{10}) or a number median (D_{av}). lationship fits his data closely, the author did not though he gives no details on geometry. He also gives h his other atomization performance data. His data irect but the data from which the exponents on data.						
						ψ, functional relationship, not defined.
$C_{TT}(g_L\mu_j^4/\rho_g\sigma_j^3)^{0.25}k_{\mu j}$	0	1.00	Note: $k_{\mu j}$ differs from unity only for very high liquid viscosities; at reference conditions $k_{\mu j}$ = 1.010	4710 (for C_{TT} = 47)	471 (for C_{TT} = 47)	Stationary jet; very long cylindrical discharge opening.
$C_{TT}(g_L\mu_j/\rho_g u_r^3)^{0.25}k_{\mu j}$	0	0.25				
$C_{TT}(g_L\rho_j^3 D_j^3/\rho_g\mu_j^2)^{0.25}k_{\mu j}$	0.75	0.25		7100 (for C_{TT} = 70.5)	710 (for C_{TT} = 70.5)	
$5.64k_{\mu j}/N_{vj}^{0.25}$	0.25	0.25	N_{vj} = 1 The value for $k_{\mu j}$ does not deviate from unity except at extremely high values of viscosity. These values could not be reconciled with the authors' data.	1000	316	Based on extrapolation of relationship given by Tanasawa and Kobayasi in Table III-C, for a swirl jet, to the case of a simple jet [i.e. for $(A_i/A_j)(D_j/D_c) = \infty$]
$597(u_j\mu_g/\sigma_j)^{1/12}k_{\rho g}$	5/6	1/2	N_p = 1 atm $u_j = u_r$	986	55.4	Stationary jet into flowing air stream; the quantity $(u_j\mu_g/\sigma_j)^{1/12}$ varies from 0.5 to 0.7 for the range of conditions covered by the authors.
$97\left(\frac{\mu_g}{\mu_j}\right)^{1/12}\left(\frac{u_j}{u_r}\right)^{1/12}k_{\rho g}$	5/6	5/12				
$97\left(\frac{\mu_g}{D_j\rho_j u_r}\right)^{1/12}\left(\frac{u_j}{u_r}\right)^{1/12}k_{\rho g}$	3/4	5/12	N_p = 1 atm $u_j = u_r/100$	671	37.8	
$97\left(\frac{D_j\rho_j u_j}{\mu_j}\right)^{1/12}\left(\frac{\mu_g}{\mu_j}\right)^{1/12}k_{\rho g}$	11/12	5/12				

Table III

SUMMARY OF DATA ON HYDRAULIC (OR PRESSURE)

B. Impinging Jet

AUTHOR	UNITS REQUIRED	EXPANDED RELATIONSHIP FOR AVERAGE DIAMETER	CONVERSION TO GENERALIZED FORMAT: $(D_{xx}/D$ (Note: Since these are all stationary axial- Type Diameter Ratio (D_{xx}/D_j)	Controlling Variables Assumed	k
Dombrowski and Hooper (1962) $0.0012\ g/cm^3 \le \rho_g \le 0.01\ g/cm^3$	cgs	$D_{32} = 0.0458\left(\frac{\sigma_j}{\Delta p}\right)^{0.16}\left(\frac{\rho_j}{\rho_g}\right)^{0.1}$ $= \frac{0.0511\sigma_j^{0.16}}{N_{vj}^{0.16}u_j^{0.32}\rho_j^{0.06}\rho_g^{0.1}}$	D_{32}/D_j	(u_r, σ_j)	$\left(\frac{0.0511}{N_{vr}^{0.16}D_j^{0.84}}\right.$
$0.01\ g/cm^3 \le \rho_g \le 0.016\ g/cm^3$	cgs	$D_{32} = 0.0726\left(\frac{\sigma_j}{\Delta p}\right)^{0.16}$ $= \frac{0.0811\sigma_j^{0.16}}{N_{vj}^{0.16}u_j^{0.32}\rho_j^{0.16}}$	D_{32}/D_j	(u_r, σ_j)	$\left(\frac{0.081}{N_{vr}^{0.16}D_j^{0}}\right.$
$0.016\ g/cm^3 \le \rho_g \le 0.025\ g/cm^3$	cgs	$D_{32} = 0.435\left[\frac{\sigma_j^{0.12}}{\Delta p^{0.2}}\right]\left(\frac{\rho_g}{\rho_j}\right)^{0.25}$ $= \frac{0.499\ \rho_g^{0.25}\sigma_j^{0.12}}{N_{vj}^{0.2}u_j^{0.4}\rho_j^{0.45}}$	D_{32}/D_j	(u_r, σ_j)	$\left(\frac{0.499\rho_g}{N_{vr}^{0.2}D_j^{0.72}\rho_j^{0}}\right.$
Dombrowski and Hooper (1964)	cgs	$D_{32} = \frac{4}{[\sin(\theta_n/2)]^{1.16}u_j^{0.79}}$	D_{32}/D_j	(u_r, value of β assumed)	$\frac{4\rho_j^{0.5}}{[\sin(\theta_n/2)]^{1.16}D}$
Kuznetsov and Talaf (1957) Authors' Equation	consistent	$D_{xx} = 513\ D_j N_{Rejj}^{-1.18} N_{Frj}^{[0.082+0.0306\ ln(N_{Rejj}^2/N_{Frj})]}$ $= \frac{513\ \mu_j^{1.18}}{g_L^{0.082+\gamma}D_j^{0.262+\gamma}u_j^{1.016-2\gamma}\rho_j^{1.18}}$	D_{xx}/D_j	(D_j, u_r)	$513\left[\frac{\rho_j\sigma_j^3}{g_L\mu_j^4}\right]$
			where $\gamma = 0.0306\ ln\ (N_{Rejj}^2/N_{Frj})$		
Equivalent Approximation	consistent	$D_{xx} = \frac{13.3D_j^{0.40}\mu_j^{0.517}}{g_L^{0.083}u_j^{0.35}\rho_j^{0.517}}$	D_{xx}/D_j	(D_j, u_r)	$13.3\left[\frac{\rho_j\sigma}{g_L\mu}\right.$
Mugele (1960)	consistent	$D_{32} = \frac{5.0\ D_j^{0.65}\mu_j^{0.15}\sigma_j^{0.20}}{u_j^{0.55}\rho_j^{0.35}}$	D_{32}/D_j	any	5
Tanasawa, Sasaki and Nagai (1957)	consistent	$D_{32} = \frac{1.73\ D_j^{0.75}\mu_j^{0}\sigma_j^{0.25}}{u_j^{0.5}\rho_j^{0.25}}$	D_{32}/D_j	any	1.73

Table III

...RAULIC (OR PRESSURE) ATOMIZATION (Continued)

B. Impinging Jet

...LIZED FORMAT: $(D_{xx}/D_j) = k/N^{\alpha}_{Rej,r}N^{\beta}_{Cej,r} = k/N^{\alpha-\beta}_{Rej,r}N^{\beta}_{Wej,r}$ ...e all stationary axial-jet nozzles, u_j and u_r are identical)				COMPARISON OF PARTICLE SIZE PREDICTION AT STANDARD REFERENCE CONDITIONS (see Table VI)			REMARKS
...ing ...es ...d	k	α	β	Additional Specifications For Reference Conditions	Average Diameter Calculated at Standard Reference Conditions, D_{xx}, Microns		
					u_r = 1,000 cm/sec	u_r = 10,000 cm/sec	
...)	$\left(\frac{0.0511}{N_{vr}^{0.16}D_j^{0.84}}\right)\left(\frac{\rho_j}{\rho_g}\right)^{0.1}$	0.16	0.16	$N_{vj} = 1$	234	112	Two 0.053-cm diameter holes impinging at an angle of 110°
...)	$\left(\frac{0.0811}{N_{vr}^{0.16}D_j^{0.84}}\right)$	0.16	0.16	$N_{vj} = 1$	186*	89*	
...)	$\left(\frac{0.499\rho_g^{0.25}}{N_{vr}^{0.2}D_j^{0.72}\rho_j^{0.17}\mu_j^{0.16}}\right)$	0.28	0.12	$N_{vj} = 1$	98*	39.1*	
					*Calculated diameter at conditions out of the range of gas phase density, ρ_g, specified for equation.		
...lue ...d)	$\frac{4\rho_j^{0.59}}{[\sin(\theta_n/2)]^{1.16}D_j^{0.41}\mu_j^{0.39}\sigma_j^{0.2}}$	0.59	0.2 (assumed)	θ_n = 90°	255	41.3	For turbulent jets; laminar jets are also studied but the results are more complex, however order of magnitude of droplet size is the same for laminar jets.
				θ_n = 180°	171	27.6	
...)	$513\left[\frac{\rho_j\sigma_j^3}{g_L\mu_j^4}\right]^{0.082+\gamma}$	$1,262 + \gamma$	$-(0.246 + 3\gamma)$		283	100	Liquid jet impinging on a deflector plate. Studied water with various velocities and liquid discharge opening diameters.
...0.0306 $\ln(N^2_{Rejj}/N_{Frj}) = 0.0306 \ln[g_L\rho_j^2D_j^3/\mu_j^2]$							
...)	$13.3\left[\frac{\rho_j\sigma_j^3}{g_L\mu_j^4}\right]^{0.083}$	0.60	-0.25		246	110	
	5	0.35	0.20		315	88.8	
	1.73	0.25	0.25		308	97.5	Head-on impingement; (θ_n = 180°)

Table III

SUMMARY OF DATA ON HYDRAULIC (OR PRESSU

C. Swirl Jet

AUTHOR	UNITS REQUIRED	EXPANDED RELATIONSHIP FOR AVERAGE DIAMETER	CONVERSION TO GENERALIZED FORMAT: FOR STATIONARY SWIRL NOZZLES: and $\Delta p = N_{vj}(\rho_j u_j^2/2)$ o Type Diameter Ratio D_{xx}/D_j	Controlling Variables Assumed	
Joyce (1949, 1953)		$D_{32} = \frac{K_{JO}D_j^{0.5}\mu_j^{0.2}}{\Delta_p^{0.4}\rho_j^{0.2}} = \frac{K'_{JO}D_j^{0.5}\mu_j^{0.2}}{N_{vr}^{0.4}u_r^{0.8}\rho_j^{0.6}}$	D_{32}/D_j	(D_j, u_r)	K_{JO} … / $N_{vr}^{0.4}\rho_j^{0.}$ …
Knight (1955) (In discussion of Radcliffe's paper)	cgs	$D_{32} = \frac{15.1u_j^{0.209}\mu_j^{0.215}}{\Delta_p^{0.458}\rho_j^{0.215}} = \frac{14.3D_j^{0.418}u_j^{0.209}\mu_j^{0.215}}{\Delta_p^{0.458}\rho_j^{0.006}}$	D_{32}/D_j	(D_j, u_r)	19 … / $N_{vr}^{0.353}N_v$ …
		$= \frac{19.6D_j^{0.418}\mu_j^{0.215}}{N_{vj}^{0.105}N_{vr}^{0.353}u_r^{0.707}\rho_j^{0.464}}$		(ρ_j, μ_j)	1 … / $N_{vr}^{0.353}N$ …
Il'yashenko and Talantov (1964)	consistent	$D_{mv} = \frac{0.00212k_{\mu j}C_q c^{0.817}D_j\sigma_j^{0.77}}{k_{pg}u_r^{0.817}}$	D_{mv}/D_j	(D_j, u_r)	$0.00212k_{\mu j}C_q$ …
		where		$(D_j,$ [illegible]$)$	$0.00212k_{\mu j}C_q$ …
		$k_{\mu j} = 1 + 66.0\mu_j^{0.44}/\rho_j^{0.44}\sigma_j^{0.77}$ $k_{pg} = N_p^{1/3}$		(σ_j, u_r)	$0.00212k_{\mu j}C_q$ …
Longwell (1943) [As quoted by Marshall (1954) and McIrvine (1957)]	cgs	$D_{mv} = \frac{23.5D_j e^{(0.705\mu_j/\rho_j)}}{\Delta p^{0.375}[\sin(\theta_m/2)]} = \frac{30.5D_j e^{(0.705\mu_j/\rho_j)}}{N_{vr}^{0.375}[\sin(\theta_m/2)]u_j^{0.75}\rho_j^{0.375}}$	D_{mv}/D_j	(D_j, u_r)	30 … / $N_{vr}^{0.375}$ …
		There is some question as to the units used by both Marshall and McIrvine in report … The value 30.5 was obtained on the assumption that both reported D_{mv} and D_j in the … used the units indicated by McIrvine the results would be unreasonable.			
McIrvine (1957)		$D_{mv} = \frac{K_{MI}D_j^{1.28}\mu_j^{0.19}\sigma_j^{0.24}}{\Delta p^{0.33}} = \frac{K'_{MI}D_j^{1.28}\mu_j^{0.19}\sigma_j^{0.24}}{N_{vr}^{0.33}u_r^{0.66}\rho_j^{0.33}}$	D_{mv}/D_j	(D_j, u_j)	K'_{MI} … / $N_{vr}^{0.33}$ …
		Note: In arriving at above exponents on D_j author ignored additional diameter effects inherent in such terms as flow rate used by other authors in their correlations. Making such allowances the exponent on D_j would be closer to 0.66		(u_j, σ_j)	$K'_{MI}D_j^{0.}$ …
				(u_j, μ_j)	$K_{MI}D_j$ … / N …
Mugele (1960)	consistent	$D_{32} = \frac{5.0D_j^{0.65}\mu_j^{0.15}\sigma_j^{0.20}}{(N_{vj}/N_{vr})^{0.163}u_r^{0.55}\rho_j^{0.35}}$ The author is not clear on the definition of terms and the exponent on the ratio (N_{vj}/N_{vr}) may not reflect the author's intent.	D_{32}/D_j	any	… / $(N_{vj}/N$ …
Nelson and Stevens (1961) — Author's Equation — Organic Liquids	consistent	$D_{mv} = D_j \exp(-0.0352Z^2 + 0.124Z - 0.429)$ where $Z = \ln\{N_{Reja}^{0.45}N_{Weja}^{0.55}[\tan(\theta_m/2)]^{1.2}\}$			
Water	consistent	$D_{mv} = D_j \exp(-0.0624Z^2 + 0.702Z - 2.900)$ where $Z = \ln\{N_{Reja}^{0.8}N_{Weja}^{0.2}[\tan(\theta_m/2)]^{1.2}\}$			
Equivalent Approximate Equation — Organic Liquids	consistent	$D_{mv} = \frac{13.0D_j^{0.47}\rho_g^{0}\mu_j^{0.24}\sigma_j^{0.29}}{[\tan(\theta_m/2)]^{0.64}u_{ja}^{0.82}\rho_j^{0.53}}$	D_{mv}/D_j	any with fixed geometry	13.0 … / [tan …
Water	consistent	$D_{mv} = \frac{23.0D_j^{0.47}\rho_g^{0}\mu_j^{0.42}\sigma_j^{0.11}}{[\tan(\theta_m/2)]^{0.64}u_{ja}^{0.64}\rho_j^{0.53}}$	D_{mv}/D_j	any with fixed geometry	23.0 … / [ta …

Table III

AULIC (OR PRESSURE) ATOMIZATION (Continued)

C. Swirl Jet

ERALIZED FORMAT: $(D_{xx}/D_j) = k/N^{\alpha}_{Rejr}N^{\beta}_{Cajr} = k/N^{\alpha-\beta}_{Rejr}N^{\beta}_{Wejr}$

SWIRL NOZZLES: $\Delta p = N_{vr}(\rho_j u_r^2/2)$ or $u_r = (2\Delta p/N_{vr}\rho_j)^{1/2}$

$N_{vj}(\rho_j u_j^2/2)$ or $u_j = (2\Delta p/N_{vj}\rho_j)^{1/2} = u_r(N_{vr}/N_{vj})^{1/2}$

k	α	β	Additional Specifications for Reference Conditions	Average Diameter Calculated at Standard Reference Conditions, D_{xx}, Microns: u_r = 1,000 cm/sec	u_r = 10,000 cm/sec	REMARKS
			COMPARISON OF PARTICLE SIZE PREDICTIONS AT STANDARD REFERENCE CONDITIONS (SEE TABLE VI)			
$\dfrac{K_{JO}}{N_{vr}^{0.4}\rho_j^{0.1}\sigma_j^{0.3}}$	0.5	0.3				K'_{JO} K_{JO} not defined. Power on a viscosity interpreted by Radcliffe (1954). See Putnam (1957) for comparison with simple jets (Table III-A).
$\dfrac{19.6\rho_j^{0.118}}{N_{vr}^{0.353}N_{vj}^{0.105}\mu_j^{0.242}\sigma_j^{0.125}}$	0.582	0.125	N_{vj} = 1	73.5	14.5	Based on the data of Lubbock and Bowen (1948) and others on Lucas burners.
$\dfrac{19.6u_r^{0.006}}{N_{vr}^{0.353}N_{vj}^{0.105}D_j^{0.118}\sigma^{0.249}}$	0.464	0.249	N_{vj} = 10	57.7	11.3	
$0.00212k_{\mu j}C_q c^{0.817}\mu_j^{0.817}/k_{pg}\sigma_j^{0.047}$	0	0.817		1483	226	
$0.00212k_{\mu j}C_q c^{0.817}\mu_j^{0.77}/k_{pg}u_r^{0.047}$	0	0.77				
$0.00212k_{\mu j}C_q c^{0.817}D_j^{0.047}\rho_j^{0.047}\mu_j^{0.723}/k_{pg}$	0.047	0.77				
$\dfrac{30.5e^{(0.705\mu_j/\rho_j)}\mu_j^{0.75}}{N_{vr}^{0.375}[\sin(\theta_m/2)]\rho_j^{0.375}\sigma_j^{0.75}}$	0	0.75		102	18.1	Tangential-entry nozzle.
$\dfrac{K'_{MI}\mu_j^{1.41}}{N_{vr}^{0.33}\rho_j^{0.61}\sigma_j^{0.70}}$	-0.28	0.94				Based on an average of values reported in the literature. No value is given for K_{MI} (or K'_{MI}).
$\dfrac{K'_{MI}D_j^{0.70}\rho_j^{0.09}\sigma_j^{0.01}}{N_{vr}^{0.33}}$	0.42	0.24				
$\dfrac{K'_{MI}D_j^{0.71}\rho_j^{0.10}}{N_{vr}^{0.33}}$	0.43	0.24				
$\dfrac{5.0}{(N_{vj}/N_{vr})^{0.163}}$	0.35	0.20	N_{vj} = 1	115	32.4	
			(u_r/u_{ja}) = 1	187	25.5	
			(u_r/u_{ja}) = 1	214	45.2	Grooved-core nozzle with interchangeable orifice inserts.
$\dfrac{13.0(u_r/u_{ja})^{0.82}}{[\tan(\theta_m/2)]^{0.64}}$	0.53	0.29	(u_r/u_{ja}) = 1	192	29.1	
$\dfrac{23.0(u_r/u_{ja})^{0.64}}{[\tan(\theta_m/2)]^{0.64}}$	0.53	0.11	(u_r/u_{ja}) = 1	225	51.7	

vine in reporting Longwell's results.
and D_j in the same units. If they
e.

Table III

SUMMARY OF DATA ON HYDRAULIC (OR PRESSURE) A

C. Swirl Jet

AUTHOR	UNITS REQUIRED	EXPANDED RELATIONSHIP FOR AVERAGE DIAMETER	CONVERSION TO GENERALIZED FORMAT: FOR STATIONARY SWIRL NOZZLES: Δ and $\Delta p = N_{vj}(\rho_j u_j^2/2)$ or		
			Type Diameter Ratio D_{xx}/D_j	Controlling Variables Assumed	
Radcliffe (1954)(1955) — Lucas Atomizers	cgs	$D_{32} = \dfrac{2.63 w_j^{0.25}}{\Delta p^{0.4}} = \dfrac{3.27 D_j^{0.5}}{N_{vj}^{0.125} N_{vr}^{0.275} u_r^{0.55} \rho_j^{0.15}}$	D_{32}/D_j	(D_j, u_r)	$\overline{N_{vj}^{0.125}}$
Power Jets (vented)	cgs	$D_{32} = \dfrac{17.60 w_j^{0.3}}{\Delta p^{0.5}} = \dfrac{23.1 D_j^{0.6}}{N_{vj}^{0.15} N_{vr}^{0.35} u_r^{0.7} \rho_j^{0.2}}$	D_{32}/D_j	(D_j, u_r)	$\overline{N_{vj}^{0.1}}$
Power Jets (vent closed)	cgs	$D_{32} = \dfrac{23.0 w_j^{0.318}}{\Delta p^{0.530}} = \dfrac{30.7 D_j^{0.636}}{N_{vj}^{0.159} N_{vr}^{0.371} u_r^{0.742} \rho_j^{0.212}}$	D_{32}/D_j	(D_j, u_r)	30 / $N_{vj}^{0.}$
Tanasawa and Kobayasi (1955)	consistent	$D_{32} = \dfrac{4.74 k_{ng} k_{na}^{9/4} k_{\mu j} D_j^{3/4} \sigma_j^{1/4}}{\Delta p^{1/4}} = \dfrac{5.64 k_{ng} k_{na}^{9/4} k_{\mu j} D_j^{3/4} \sigma_j^{1/4}}{N_{vr}^{1/4} u_r^{1/2} \rho_j^{1/4}}$	D_{32}/D_j	any	5.6
		where: $k_{ng} = [1 + 0.37\sqrt{L_{nj}/D_j}][1 + 19.7 \exp - [(4.13)(A_i/A_j)(D_j/D_c)]$ $k_{na} = [1 - (D_{ac}/D_j)]$ $k_{\mu j} = [1 + 15.56(N_{Ohjj}/k_{na})^{3/2}] = [1 + 15.56(\mu_j^2/k_{na} D_j \rho_j \sigma_j)^{3/2}]$			All correlatio which were cal tial flow theo N_{vj}, (D_{ac}/D_j) etry as measur The potential $(A_i/A_j)(D_j/D_c$ 0.0 0.1 0.2 0.3 0.5 0.7 1.0 2.0 ∞
Tate and Marshall (1953)	cgs	$D_{32} = 0.01126(D_j + 0.43) e^{[(396/u_j) - (u_{jit}/3240)]}$			
Turner and Moulton (1953) — Tangential-Entry Nozzle	cgs	$D_{lav} = \dfrac{0.442 D_j^{1.589} \mu_j^{0.220} \sigma_j^{0.594}}{w_j^{0.537}} = \dfrac{0.504 D_j^{0.515} \mu_j^{0.220} \sigma_j^{0.594}}{u_j^{0.537} \rho_j^{0.537}}$	D_{lav}/D_j	(D_j, u_r) with fixed velocity ratio (u_r/u_j)	0.504
Grooved-Core Nozzle	cgs	$D_{lav} = \dfrac{0.1140 D_j^{1.520} \mu_j^{0.159} \sigma_j^{0.713}}{w_j^{0.444}} = \dfrac{0.127 D_j^{0.632} \mu_j^{0.159} \sigma_j^{0.713}}{u_j^{0.444} \rho_j^{0.444}}$	D_{lav}/D_j	(D_j, u_r) with fixed velocity ratio (u_r/u_j)	0.127

Table III

DRAULIC (OR PRESSURE) ATOMIZATION (Concluded)

C. Swirl Jet

O GENERALIZED FORMAT: $(D_{xx}/D_j) = k/N^{\alpha}_{Rejr}N^{\beta}_{Cajr} = k/N^{\alpha-\beta}_{Rejr}N^{\beta}_{Wejr}$

ONARY SWIRL NOZZLES: $\Delta p = N_{vr}(\rho_j u_r^2/2)$ or $u_r = (2\Delta p/N_{vr}\rho_j)^{1/2}$

$= N_{vj}(\rho_j u_j^2/2)$ or $u_j = (2\Delta p/N_{vj}\rho_j)^{1/2} = u_r(N_{vr}/N_{vj})^{1/2}$

trolling riables sumed	k	α	β	COMPARISON OF PARTICLE SIZE PREDICTIONS AT STANDARD REFERENCE CONDITIONS (SEE TABLE VI): Additional Specifications for Reference Conditions	Average Diameter Calculated at Standard Reference Conditions, D_{xx}, Microns: u_r = 1,000 cm/sec	u_r = 10,000 cm/sec	REMARKS
$_j, u_r)$	$\dfrac{3.27\rho_j^{0.35}}{N_{vj}^{0.125}N_{vr}^{0.275}\mu_j^{0.45}\sigma_j^{0.05}}$	0.5	0.5	N_{vj} = 1	92.3	26.0	Correlation based on Needham's data.
				N_{vj} = 10	69.2	19.5	
$_j, u_r)$	$\dfrac{23.1\rho_j^{0.2}}{N_{vj}^{0.15}N_{vr}^{0.35}\mu_j^{0.1}\sigma_j^{0.3}}$	0.4	0.3	N_{vj} = 1	146	29.1	
				N_{vj} = 10	103	20.6	
$_j, u_r)$	$\dfrac{30.7\rho_j^{0.152}\mu_j^{0.014}}{N_{vj}^{0.159}N_{vr}^{0.371}\sigma_j^{0.378}}$	0.364	0.378	N_{vj} = 1	124	22.5	
				N_{vj} = 10	86.0	15.6	
any	$5.64k_{ng}k_{na}^{9/4}k_{\mu j}/N_{vr}^{1/4}$	0.25	0.25	$(L_{nj}/D_j) = 0$ $(A_i/A_j) = 1$ $(D_j/D_c) = 0.3$	315	100	The term $k_{\mu j}$ is appreciably different from unity at very high liquid viscosities. At the standard reference conditions, $k_{\mu j}$ is essentially unity. The actual values of $k_{\mu j}$ do not deviate from unity except at extremely high values of viscosity and cannot be reconciled with the authors' data.
	All correlations were based on the following values which were calculated by the authors assuming potential flow theory. The following tabulation gives N_{vj}, (D_{ac}/D_j), and θ_a as a function of nozzle geometry as measured by the grouping $(A_i/A_j)(D_j/D_c)$. The potential flow assumption would also imply N_{vr} = 1.						
				(u_{jit}/u_j) = 1	65	2.8	Grooved-core nozzle.
$_j, u_r)$ h fixed locity ratio $_r/u_j)$	$\dfrac{0.504\sigma_j^{0.542}(N_{vj}/N_{vr})^{0.268}}{\rho_j^{0.052}\mu_j^{0.213}}$	0.485	0.052	N_{vj} = 1	211	61.2	Tangential-entry nozzle.
				N_{vj} = 10	390	114	
$_j, u_r)$ h fixed locity ratio $_r/u_j)$	$\dfrac{0.127\sigma_j^{0.637}(N_{vj}/N_{vr})^{0.222}}{\rho_j^{0.076}\mu_j^{0.133}}$	0.368	0.076	N_{vj} = 1	177	63.7	Grooved-core nozzle.
				N_{vj} = 10	295	106	

$(A_i/A_j)(D_j/D_c)$	N_{vj}	(D_{ac}/D_j)	θ_a, degrees
0.0	∞	1.000	180
0.1	129.0	0.866	121
0.2	39.0	0.799	106
0.3	19.9	0.744	95.8
0.5	9.36	0.659	82.3
0.7	5.29	0.592	72.4
1.0	3.75	0.516	61.7
2.0	1.94	0.358	42.0
∞	1.00	0.000	0.0

Table IV

SUMMARY OF DATA ON PNEUMATIC (TWO

AUTHOR	UNITS REQUIRED	EXPANDED RELATIONSHIP FOR AVERAGE DIAMETER	CONVERSION TO GENERA	
			Type Diameter Ratio (D_{xx}/D_j)	Controlling Variables Assumed
Gretzinger and Marshall (1961) convergent type	cgs	$D_{av} = 0.260\left[\left(\frac{w_j}{w_g}\right)\left(\frac{\mu_g}{G_g D_{jw}}\right)\right]^{0.4} = \frac{0.260\,\rho_j^{0.4}\mu_g^{0.4}(q_j/q_g)^{0.4}}{D_{jw}^{0.4}u_g^{0.4}\rho_g^{0.8}}$	D_{av}/D_j	(D_j, u_r) With fixed geometry, fixed volumetric lo ing (q_j/q_g), and fi (u_g/u_r)
impingement type	cgs	$D_{av} = 0.0122\,(w_j/w_g)^{0.6}(\mu_g/G_g D_{jw})^{0.15} = \frac{0.0122\,\rho_j^{0.6}\mu_g^{0.15}(q_j/q_g)^{0.6}}{D_{jw}^{0.15}u_g^{0.15}\rho_g^{0.75}}$	D_{av}/D_j	(D_j, u_r) With fixed geometry, fixed volumetric lo ing, and fixed (u_g/u
Kim (1959)	cgs	$D_{av} = \frac{0.842\,\mu_j^{0.323}\sigma_j^{0.411}k_q}{D_{ge}^{0.733}D_j^0 u_r^{1.144}\rho_g^{0.572}\rho_j^{0.161}}$ where $k_q = 1 + 2.25\,[D_{ge}^{0.733}u_r^{0.604}\rho_g^{0.572}\mu_j^{0.017}/\rho_j^{0.009}\sigma_j^{0.581}][w_j/w_g]^{n_w}$ $n_w = 1$ for $w_j/w_g > 0.3$ $n_w = 0.5$ for $w_j/w_g < 0.3$ Note: Kim reported his correlations in two formats: one gives drop diameter in terms of dimensionless groups; the other in terms of common units. There is a discrepancy between the two, the former giving drop sizes which are 1.45 times larger than the latter. The former is the basis for the results reported here.	D_{av}/D_j	(D_j, u_r) With fixed geometr (u_r, σ_j) or (u_r, μ_j)
Mugele (1960)	consistent	$D_{32} = \frac{1140\,D_j^{0.18}\,\mu_j^{0.37}\sigma_j^{0.45}}{u_r^{1.27}\rho_j^{0.82}}$	D_{32}/D_j	any
Nukiyama and Tanasawa (1939)	cgs	$D_{32} = \frac{5.85\,\sigma_j^{0.5}k_q}{u_r\rho_j^{0.5}}$ where $k_q = 1 + 323\,(u_r\rho_j^{0.275}\mu_j^{0.45}/\sigma_j^{0.725})(q_j/q_g)^{1.5}$ $= 1 + (323/D_j^{0.275})(N_{We j r}^{0.725}/N_{Re j r}^{0.450})(q_j/q_g)^{1.5}$	D_{32}/D_j	(D_j, u_r) (u_r, σ_j)
Plit (1962) for $u_g < u_{gcr}$	consistent	$D_{32} = \left[\frac{1.83\,k_{ng}k_q}{g_L^{0.1}}\right]\frac{D_j^{0.28}\mu_j^{0.04}\sigma_j^{0.58}}{u_g^{1.00}\rho_j^{0.10}\rho_g^{0.52}}$ where $k_q = (q_j/q_g)^{0.54}$ $k_{ng} = k_{nt}(D_g/D_{go})^{0.48}(D_j/D_{go})^{0.42}(1 + 0.573\,\theta_D)[1 + 0.05\,(L_j/D_g)]$ $k_{nt} = (D_{g1}/D_j)^{0.6}$ for 2-tube nozzle $k_{nt} = [(D_j + D_{g1})/D_j]^{0.6}(D_{jo}/D_j)^{0.1}$ for 3-tube nozzle	D_{32}/D_j	(D_j, u_r) with fixed ratio (u_g/u_r)
			Note:	This article conta reports that the calculating partic equation. It was versely as either power, varying fr such phenomenon i for critical veloc the author present The author covere
Wetzel and Marshall (1954) (as quoted by Marshall, 1954) wax	cgs	$D_{av} = 94200\,D_j^{0.35}/u_r^{1.68}$	D_{av}/D_j	(D_j, u_r)
alloy (low melting)	cgs	$D_{av} = 444/u_r^{1.11}$	D_{av}/D_j	u_r; value of expon α was assumed
Wigg (1960)	consistent (except for k_r which requires cgs units)	$D_{av} = \frac{19.0\,L_g^{0.1}w_j^{0.1}\mu_j^{0.5}\sigma_j^{0.2}k_q k_r}{u_r\rho_j^{0.5}\rho_q^{0.3}} = \frac{18.5\,L_g^{0.1}D_{je}^{0.2}u_j^{0.1}\mu_j^{0.5}\sigma_j^{0.2}k_q k_r}{u_r\rho_j^{0.4}\rho_g^{0.3}}$ where $k_q = [1 + (w_j/w_g)]^{0.5}$ $k_r = 1 + 2.6\,w_j^{0.1}(w_j/w_g)^{0.6}$	D_{av}/D_j	(D_j, u_r) with fixed geomet (D_j, u_r) with fixed geome and (u_j/u_r)-rati (D_{je}, u_r) (D_{je}, σ_j) or (σ_j, u_r) (All assume D_j = D

Table IV

[illegible]TA ON PNEUMATIC (TWO FLUID) ATOMIZATION

[illegible]ONVERSION TO GENERALIZED FORMAT: $(D_{xx}/L_j) = k/N^{\alpha}_{Rejr}N^{\beta}_{Cajr} = N^{\alpha-\beta}_{Rejr}N^{\beta}_{Wejr}$				COMPARISON OF PARTICLE SIZE PREDICTION AT STANDARD REFERENCE CONDITION (See Table VI)			
Controlling Variables Assumed	k	α	β	Additional Specifications for Reference Conditions	Average Diameter Calculated at Standard Reference Conditions, D_{xx}, Microns: u_r = 1,000 cm/sec	u_r = 10,000 cm/sec	REMARKS
(D_j, u_r) With fixed geometry, fixed volumetric loading (q_j/q_g), and fixed (u_g/u_r)	$\frac{0.260\ (\rho_j/\rho_g)^{0.8}(\rho_j\sigma_j/\mu_j^2)(q_j/q_g)^{0.4}}{(D_{jw}/D_j)^{0.4}(\mu_j/\mu_g)^{0.4}(u_g/u_r)^{0.4}}$	1.4	-1.0	$(D_{jw}/D_j) = 1$ $(w_j/w_g) = 1$ $(u_g/u_r) = 1$	164	65.3	Essentially an external-mix nozzle; air discharge velocities are sonic; μ_g was not varied.
(D_j, u_r) With fixed geometry, fixed volumetric loading, and fixed (u_g/u_r)	$\frac{0.0122\ (\rho_j/\rho_g)^{0.75}(\rho_j\sigma_j/\mu_j^2)(q_j/q_g)^{0.6}}{(D_{jw}/D_j)^{0.15}(\mu_j/\mu_g)^{0.15}(u_g/u_r)^{0.15}}$	1.15	-1.0	$(D_{jw}/D_j) = 1$ $(w_j/w_g) = 1$ $(u_g/u_r) = 1$	43.3	30.6	Correlation is for $w_j/w_g > 0.1$
(D_j, u_r) With fixed geometry	$0.842\ (\rho_j/\rho_g)^{0.572}(\rho_j\sigma_j/\mu_j^2)k_q(D_j/D_{ge})^{0.733}$	1.733	-0.589	$(D_{ge}/D_j) = 1$ $(w_j/w_g) = 0$	1314	94.3	Essentially external-mix nozzle; also gives similar correlation for double air nozzle type atomizer
(u_r, σ_j) or (u_r, μ_j)	$0.842\ (\rho_j/\rho_g)^{0.572}k_q(1/D_{ge})(D_j/D_{ge})^{0.733}$	0.733	0.411	$(D_{ge}/D_j) = 1$ $(w_j/w_g) = 1$	1363	107.8	
any	1140	0.82	0.45	$(q_j/q_g) < 0.0001$	1686	90.5	Correlation for low liquid loading $(q_j/q_g < 0.0001)$
(D_j, u_r)	$5.85\ \rho_j^{0.5}\sigma_j^{0.5}k_q/\mu_j$	1.0	0	$(w_j/w_g) = 0$	585	58.5	Internal mix nozzles
(u_r, σ_j)	$5.85\ k_q/D_j^{0.5}$	0.5	0.5	$(w_j/w_g) = 1$	612	85.2	
(D_j, u_r) with fixed ratio (u_g/u_r)	$\frac{1.83\ k_{ng}k_q\rho_j^{0.62}\sigma_j^{0.30}}{g_L^{0.1}\rho_g^{0.52}\mu_j^{0.40}(u_g/u_r)}$	0.72	0.28	$(w_j/w_g) = 1$ $k_{ng} = 1$ $u_g = u_r$	50.4	5.0	Combination mix nozzles: (a) 2-tube nozzle consists of two concentric tubes, center tube having a serrated tip. Liquid admitted to the inner edge of center tube; air flows through both tubes; (b) 3-tube nozzle consists of three concentric tubes converging at the discharge end. Liquid enters the annulus between the center and the second tube; air enters the center and the outside tube.
[illegible]te: This article contains numerous typographical errors and inconsistencies, many of which could not be resolved. This author reports that the arithmetic mean diameter was measured. Actually his method measures a Sauter diameter. His equation for calculating particle size also seems to be in error by a factor of $(3/2)^2$, the actual size being larger than shown by his equation. It was not possible to reconcile his plotr with his equations. His equations show drop diameter varying inversely as either the square root or first power of gas velocity; his plots show this variation to be closer to the second power, varying from 1 to 3. He reports a critical velocity at which drop size variation with gas velocity changes. No such phenomenon is apparent from his graphs, nor can his equations for this critical velocity be reconciled with the curves for criticel velocity presented in his graphs. The equations given here are direct algebraic conversions from the equations the author presented ignoring the above problems. Only the equations for velocities less than the critical are presented. The author covered a gas velocity range of 25 to 75 m/sec with drops in the size range of 30 to 500 microns diameter.							
(D_j, u_r)	$94200\ \rho_j^{0.65}\mu_j^{0.38}/\sigma_j^{1.03}$	0.65	1.03		3850	80.4	Venturi atomizer of pilot plant size.
u_r; value of exponent α was assumed	$444\ \rho_j^{0.7}/D_j^{0.3}\mu_j^{0.29}\sigma_j^{0.41}$	0.70 (assumed)	0.41		2060	159	
(D_j, u_r) with fixed geometry	$18.5(L_g/D_j)^{0.1}(D_{je}/D_j)^{0.2}(\rho_j/\rho_g)^{0.3}(u_j\mu_j/\sigma_j)^{0.1}k_qk_r$	0.7	0.3	$(L_g/D_j) = 1$			External-mix nozzle.
(D_j, u_r) with fixed geometry and (u_j/u_r)-ratio	$18.5(L_g/D_j)^{0.1}(D_{je}/D_j)^{0.2}(u_j/u_r)^{0.1}(\rho_j/\rho_g)^{0.3}k_qk_r$	0.7	0.2	$(D_{je}/D_j) = 1$	294	37.[illegible]	k_r applicable only for liquids capable of coallescing on drop collision; apparently assumes that u_r is equal to the velocity of sound for high pressure nozzles.
(D_{je}, u_r) ; (D_{je}, σ_j) : or (σ_j, u_r) (All assume $D_j = D_{je}$)	$18.5\ (L_gu_j\rho_j/\mu_j)^{0.1}(\rho_j/\rho_g)^{0.3}k_qk_r$	0.8	0.2	$(u_j/u_r) = 0.1$ $k_r = 1$ $k_q = 1$			Data based on external mix atomizer with central liquid feed tube surrounded by swirling compressed gas.

Table V

SUMMARY OF DATA ON ROTARY OR SPINN

AUTHOR	UNITS REQUIRED	EXPANDED RELATIONSHIP FOR AVERAGE DIAMETER	CONVERSION TO GENERALIZED FORMAT: (D_{xx}/D_d) = Type Diameter Ratio (D_{xx}/D_d)	Controlling Variables Assumed	k
Fraser, Dombrowski and Routley (1963)	cgs	$D_{32} = [6 \times 10^{-4}] + \left[\frac{2.75 k_{ng} k_q}{k_g}\right]\left[\frac{\Gamma_j^{0.5}\mu_j^{0.21}\sigma_j^{0.5}}{u_d^{1.5}\rho_j^{0.71}\rho_g^{0.5}}\right]$ where $k_{ng} = (L_r/D_d)^{0.25}[1 + (L_r/D_d)]^{0.25}$; $k_q = 1 + 0.065(w_j/w_g)^{1.5}$; $k_g = [1 - (u_g/u_d) + 0.5(u_g/u_d)^2]^{0.5}$; $L_r \gtrsim 0.2$ inch	D_{32}/D_d	(D_d, u_d) or (u_d, σ_j)	$\left[\frac{2.75 k_{ng} k_q}{k_g}\right]\left[\frac{\Gamma_j}{\mu_j}\right]^{0.5}\left[\frac{\rho_j}{\rho_g}\right.$ Note: This format is c additive term 6×10^{-4} i D_{32}. This term corresp particle size of 6 mic such a lower limit is qu of the author's data th with the actual drop si
Friedman, Gluckert and Marshall (1952)	consistent	$D_{32} = \frac{0.913\Gamma_j^{0.2}D_d^{0.4}L_w^{0.1}\mu_j^{0.2}\sigma_j^{0.1}}{u_d^{0.6}\rho_j^{0.5}}$	D_{32}/D_d	(D_d, u_d); (D_d, σ_j); (u_d, σ_j); or (u_d, ρ_j)	$0.913\ k_{ng}k$ where $k_{ng} = (L_w/$ $k_{qd} = (\Gamma_j/$ (Γ_j/μ_j) = Reynolds nu liquid velo = $L_f u_R \rho_j/\mu_j$ Authors report that a with k three times as their data for the max those of Walton and P
Mugele (1960)	consistent	$D_{pmax} = \frac{1.73 D_d^{0.5}\mu_j^{0.05}\sigma_j^{0.45}}{u_d^{0.95}\rho_j^{0.5}}$	D_{pmax}/D_d	any	1.73
Peskin and Lawler (1962)	consistent	$D_{xx} = 2.2\frac{D_d^{1/2}\sigma_j^{1/2}}{u_d\rho_j^{1/2}}$	D_{xx}/D_d	any	2.2
Putnam and Miesse (1957) [Based on data of Walton and Prewett (1949)]	consistent	$D_{xx} = \frac{3.32 D_d^{0.437}\mu_j^{0.082}\sigma_j^{0.481}}{u_d^{1.044}\rho_j^{0.563}}$	D_{xx}/D_d	any	3.33
Walton and Prewett (1949)	consistent	$D_{xx} = \frac{1.9 D_d^{1/2}\sigma_j^{1/2}}{u_d\rho_j^{1/2}}$	D_{xx}/D_d	any	1.9

Table V

ON ROTARY OR SPINNING DISK ATOMIZATION

ED FORMAT: $(D_{xx}/D_d) = k/N_{Rejd}^{\alpha}N_{Cajd}^{\beta} = k/N_{Rejd}^{\alpha-\beta}N_{Wejd}^{\beta}$			COMPARISON OF PARTICLE SIZE PREDICTION AT STANDARD REFERENCE CONDITIONS (see Table VI)			
k	α	β	Additional Specifications for Reference Conditions	Average Diameter Calculated at Standard Reference Conditions, D_{xx}, Microns: u_d = 1,000 cm/sec (ω_d = 1,910 rpm)	u_d = 10,000 cm/sec (ω_d = 19,100 rpm)	REMARKS
$\left[\frac{75k_{ng}k_q}{k_g}\right]\left[\frac{\Gamma_j}{\mu_j}\right]^{0.5}\left[\frac{\rho_j}{\rho_g}\right]^{0.5}\left[\frac{\mu_j}{\rho_j}\right]^{0.21}$	1	0.5	$(L_r/D_d) = 0.1$ $(w_j/w_g) = 0$ $(u_g/u_d) = 0$ $(\Gamma_j/\mu_j) = 1000$	197	12.0	Combination atomizer in which an air stream impinges at right angles on a sheet of liquid leaving a 4-inch diameter spinning disk
e: This format is derived by ignoring the itive term 6×10^{-4} in the equation defining This term corresponds to a lower limit on ticle size of 6 microns. The reality of a lower limit is questionable and for most he author's data this term is small compared the actual drop size.			$(L_r/D_d) = 0.1$ $(w_j/w_g) = 0$ $(u_g\ u_d) = 10$ $(\Gamma_j/\mu_j) = 1000$	36.5	7.0	
$0.913\ k_{ng}k_{qd}$ where $k_{ng} = (L_w/D_d)^{0.1}$ $k_{qd} = (\Gamma_j/\mu_j)^{0.2}$	0.5	0.1	$(\Gamma_j/\mu_j) = 1000$* $(L_w/D_d) = \pi$†	513	129	
$/\mu_j)$ = Reynolds number based on radial liquid velocity and film thickness $= L_f u_R \rho_j/\mu_j$ thors report that an identical expression th k three times as large fitted both eir data for the maximum drop size and ose of Walton and Prewett.			*Corresponds to a capacity of 314 g/sec (≈5.0 gpm for water) for a 10-cm diameter disk and a liquid of viscosity 1 cp. †Corresponds to a simple (non-vaned) disk.			
1.73	0.5	0.45	$(\Gamma_j/\mu_j) = 0$	488	54.8	Low liquid feed rates
2.2	1/2	1/2	$(\Gamma_j/\mu_j) = 0$	696	69.6	Theoretical; low liquid rates
3.33	0.563	0.481	$(\Gamma_j/\mu_j) = 0$	420	38.0	Low liquid rates
1.9	1/2	1/2	$(\Gamma_j/\mu_j) = 0$	601	60.1	Low liquid rates; at very low rates, main drops leave the water as single drops and are quite uniform. At higher liquid rates, the number of smaller (satellite) drops increases

Table VI

STANDARD REFERENCE CONDITIONS FOR CORRELATION COMPARISONS

FLUID PROPERTIES	NOZZLE OR DISK PROPERTIES
ρ_g = 0.001 g/cm³ = 10^{-3} g/cm³	D_d = 10 cm = 10^{1} cm
ρ_j = 1 g/cm³ = 10^{0} g/cm³	D_g = 1 cm = 10^{0} cm
μ_g = 0.01 cp = 10^{-4} poise	D_j = 0.1 cm = 10^{-1} cm
μ_j = 1 cp = 10^{-2} poise	N_{ir} = 1
σ_j = 100 dynes/cm = 10^{2} dynes/cm	θ_n = 90^0 = $\pi/2$ radian
N_p = 1 atm (where needed)	

FLOW CONDITIONS		
Velocity (u, u_j, u_g, u_r, or u_d), cm/sec	10^3	10^4
ft/sec	32.8	328.
Corresponding values of dimensionless ratios		
Capillary Number		
$N_{Caj} = u\mu_j/\sigma_j$	10^{-1}	10^{0}
Froude Numbers		
$N_{Frd} = u_d^2/g_L D_d$	1.020×10^2	1.020×10^4
$N_{Frj} = u_j^2/g_L D_j$	1.020×10^4	1.020×10^6
Ohnesorge Numbers		
$N_{Ohjd} = \mu_j^2/D_d\rho_j\sigma_j$	10^{-7}	10^{-7}
$N_{Ohjj} = \mu_j^2/D_j\rho_j\sigma_j$	10^{-5}	10^{-5}
Reynolds Numbers		
$N_{Rejd} = D_d u_d \rho_j/\mu_j$	10^6	10^7
$N_{Rejj} = D_j u_j \rho_j/\mu_j$	10^4	10^5
$N_{Rejr} = D_j u_r \rho_j/\mu_j$	10^4	10^5
$N_{Regr} = D_g u_r \rho_g/\mu_g$	10^4	10^5
Weber Numbers		
$N_{Wejd} = D_d u_d^2 \rho_j/\sigma_j$	10^5	10^7
$N_{Wejj} = D_j u_j^2 \rho_j/\sigma_j$	10^3	10^5
$N_{Wejr} = D_j u_r^2 \rho_j/\sigma_j$	10^3	10^5
$N_{Wegr} = D_g u_r^2 \rho_g/\sigma_j$	10^1	10^3
Velocity Head		
$p_{vj} = \rho_j u_j^2/2$, dynes/cm²	5.00×10^5	5.00×10^7
psi	7.25	725
ft fluid flowing	16.75	1675
$p_{vg} = \rho_g u_g^2/2$, dynes/cm²	5.00×10^2	5.00×10^4
in. water	0.200	20.0
Volumetric Flow Rates		
$q_g = u_g A_g = \pi u_g D_g^2/4$, cm³/sec	785	7850
ft³/min	1.662	16.62
$q_j = u_j A_j = \pi u_j D_j^2/4$, cm³/sec	7.85	78.5
gal/hr	7.46	74.6
Mass Flow Rates		
$w_g = \rho_g q_g$, g/sec	0.785	7.85
lb/hr	6.23	62.3
$w_j = \rho_j q_j$, g/sec	7.85	78.5
lb/hr	62.3	623
Disk Speed, u_d, cm/sec	10^3	10^4
ω_d, radians/sec	200	2,000
rpm	1,910	19,100
a_d, number of gravities	204	20,400

Table VII

SUMMARY OF DATA ON EFFECT OF VARIABLES ON MEAN DROP SIZE

TYPE OF ATOMIZER			INVESTIGATOR	POWER DEPENDENCE OF MEAN DROP SIZE ON VARIABLE INDICATED						
				Diameter* D_j	Velocity* u_r	Density		Viscosity		Surface Tension σ_j
						Liquid ρ_j	Gas ρ_g	Liquid μ_j	Gas μ_g	
Hydraulic	Simple Jet	Circular Nozzle	Harmon (1955)	0.3	-0.55	-0.648	-0.052	0.07	0.78	-0.15
			Kurabayasi (1961)		-1.15	-0.25				0.25
			Merrington and Richardson (1947)	0	-1.0	-0.2		0.2		
			Mugele (1960)	0.65	-0.55	-0.35		0.15		0.20
			Panasenkov (1951)	0.85	-0.15	-0.15		0.15		
			Pilcher and Miesse (1957)	0.5	-0.8	-0.6		0.[illegible]		
			Popov (1956)	1.15	-1.00	0.55	-0.40	1.22	0.08	1.15
			Tanasawa and Toyoda (1956)	1.00	-1.00		-0.25			0.25
			Tanasawa and Kobayasi (1955)	0.75	-0.5	-0.25				0.25
		Fan Spray	Fraser and Eisenklam (1956)	0.74	-0.50	-0.37				0.25
			Fraser, Eisenklam, and Dombrowski (1957)	0.667	-0.667	-0.500				0.333
			Hassen and Mizrahi (1961)	0.667	-0.667	-0.167		0.167		0.333
			Kruse, Hess, and Ludvik (1949)		-1.06	-1.06		1.06		1.06
		Miscellaneous or Theoretical	Mayer (1961)		-1.333	-0.333	-0.667	0.66[illegible]		0.333
			Weiss and Worsham (1959)	0.167	-1.250	-0.833	-0.4†	0.333	0.083	0.416
	Impinging Jet		Dombrowski and Hooper (1962)		-0.32 to -0.4	-0.06 to -0.45	-0.1 to +0.25			0.16 to 0.12
			Dombrowski and Hooper (1964)		-0.79					
			Kuznetsov and Tslaf (1957)	0.40	-0.35	-0.517		0.517		
			Mugele (1960)	0.65	-0.55	-0.35		0.15		0.20
			Tanasawa, Sasaki, and Nagai (1957)	0.75	-0.5	-0.25		0		0.25
	Swirl Jet		Il'yashenko and Talantov (1964)	1.00	-0.817		-0.33†			0.77
			Joyce (1949) (1953)	0.50	-0.8	-0.6		0.2		
			Knight (1955)	0.418	-0.707	-0.464		0.215		
			Longwell (1943)	1.00	-0.75	-0.375				
			McIrvine (1957)	1.28	-0.66	-0.33		0.19		0.24
			Mugele (1960)	0.65	-0.55	-0.35		0.15		0.20
			Nelson and Stevens (1961) - organic liquid	0.47	-0.82	-0.53	0	0.24		0.29
			- water	0.47	-0.64	-0.53	0	0.42		0.11
			Radcliffe (1954) (1955)	0.50 to 0.636	-0.55 to -0.742	-0.15 to -0.212				
			Tanasawa and Kobayasai (1955)	0.75	-0.50	-0.25				0.25
			Turner and Moulton (1953) - tang. entry	0.515	-0.537	-0.537		0.220		0.594
			- grooved entry	0.632	-0.444	-0.444		0.159		0.713
Pneumatic			Gretzinger and Marshall (1961) - convergent	-0.4	-0.4	0.4	-0.8		0.4	
			- impingement	-0.15	-0.15	0.6	-0.75		0.15	
			Kim (1959)	-0.733	-1.114	-0.161	-0.572	0.323		0.411
			Mugele (1960)	0.48	-1.27	-0.82		0.37		0.[illegible]5
			Nukiyama and Tanasawa (1939)		-1.00	-0.50				0.[illegible]
			Plit (1962)	0.28	-1.00	-0.10	-0.52	0.04		0.[illegible]9
			Wetzel and Marshall (1954) - wax	0.35	-1.68					
			- alloy		-1.11					
			Wigg (1960)	0.30	-1.00	-0.4	-0.3	0.5		0.2
Rotary			Fraser, Dombrowski, Routley (1963)§		-1.50	-0.71	-0.50	0.25		0.50
			Friedman, Gluckert, and Marshall (1952)	0.5	-0.6	-0.5		0.2		0.1
			Mugele (1960)	0.5	-0.95	-0.5		0.05		0.45
			Peskin and Lawler (1962)	0.5	-1.0	-0.5				0.5
			Putnam and Miesse (1957)	0.437	-1.044	-0.563		0.082		0.481
			Walton and Prewett (1949)	0.5	-1.0	-0.5				0.5

* Exponent given is net for all diameter terms or for all velocity terms.

† Author reports in different format: this is equivalent exponential effect.

§ Exponents given ignore an additive term reported by author.

APPENDIX A

ANALYTICAL RELATIONSHIPS IN ATOMIZATION

A. Dimensional Analysis

Many investigators have given a dimensional analysis of the atomization phenomenon [in particular: Baron (1949), Kuznetsov and Tslaf (1958), Mugele (1960), Plit (1963), Popov (1956), Ranz (1956), and Wigg (1960)]. This section presents an attempt at generalizing such an analysis for all types of common mechanical atomizers.

For atomization of a liquid by means of a simple jet, two-phase nozzle, or spinning disk, we may assume that the mean particle diameter is determined as follows:

$$D_{xx} = \psi[D,\ u,\ q_j,\ q_g,\ \rho_j,\ \rho_g,\ \mu_j,\ \mu_g,\ \sigma_j,\ g_L,\ c] \quad , \qquad \text{(A-1)}$$

where D is a characteristic dimension of the atomizer and u a characteristic velocity. Additional geometric ratios may also be used to describe geometric variations if needed.

By dimensional analysis, Equation A-1 may be reduced to

$$D_{xx}/D = \psi[N_{Re},\ N_{We},\ N_{Ma},\ N_{Fr},\ (\rho_j/\rho_g),\ (\mu_j/\mu_g),\ (q_j/uD^2),\ (q_g/q_j)] \quad , \qquad \text{(A-2)}$$

where

$$N_{Re} = Du\rho/\mu \quad , \qquad \text{(A-3)}$$

$$N_{We} = Du^2\rho/\sigma \quad , \qquad \text{(A-4)}$$

$$N_{Ma} = u/c \quad , \qquad \text{(A-5)}$$

$$N_{Fr} = u^2/g_L D \quad . \qquad \text{(A-6)}$$

Any subscript may be used on D, u, ρ, and μ in defining the various terms, N_{Re}, N_{We}, N_{Ma}, and N_{Fr}. The ones chosen merely establish the nature of the function ψ. Any additional geometric ratios (such as angle or dimension ratios) needed to fully describe the atomizing equipment would be added as additional dimensionless terms to Equation A-2. The term q_j/uD^2

is actually a geometric factor, since q_j, u, and D are interrelated in terms of the geometry.

In the case of a simple jet atomizer, q_g is zero and, if u and D are taken as u_j and D_j, respectively, (q_j/uD^2) becomes a constant, since

$$q_j = \pi u_j D_j^2/4 \quad . \tag{A-7}$$

Therefore, for the simple jet atomizer the last two terms of Equation A-2 will disappear.

For the spinning disk, q_g is usually zero and hence the last term of Equation A-2 disappears.

For a two-phase atomizer nozzle

$$q_j = \psi(u_j, D_j) = \pi u_j D_j^2/4 \quad , \tag{A-8}$$

$$q_g = \psi(u_g, D_g) = \pi u_g D_g^2/4 \quad , \tag{A-9}$$

$$u_r = \psi(u_j, u_g) = |\vec{u}_g - \vec{u}_j| \quad . \tag{A-10}$$

Thus, taking D and u as the dimensions and velocities specified in Equations A-8 to A-10, we have added to Equation A-2 three variables and three equations. By means of these the term (q_j/uD^2) in Equation A-2 may be replaced by a velocity ratio, *e.g.*, (u_j/u).

It should also be noted that other dimensionless numbers commonly referred to in the literature on atomization are not independent of the above. They are actually a combination of one or more of these, for example,

$$N_{Oh} = \mu^2/D\rho\sigma = N_{We}/N_{Re}^2 \quad , \tag{A-11}$$

$$N_{Ca} = u\mu/\sigma = N_{We}/N_{Re} \quad , \tag{A-12}$$

$$N_{Bo} = g_L \rho D^2/\sigma = N_{We}/N_{Fr} \quad , \tag{A-13}$$

$$N_{Ga} = g_L D^3 \rho^2/\mu^2 = N_{Re}^2/N_{Fr} \quad . \tag{A-14}$$

These combinations have certain advantages in some applications. For example, the Ohnesorge, the Bond, and the Galileo numbers are independent of fluid velocity, while the capillary number does not involve a size term.

The various dimensionless numbers are all a measure of the relative importance of certain forces, as indicated below:

Dimensionless Number	Measure of the Relative Magnitude of
Reynolds, N_{Re}	Inertial to shear forces
Weber, N_{We}	Inertial to surface forces
Froude, N_{Fr}	Inertial to hydrostatic forces
Capillary, N_{Ca}	Shear to surface forces
Bond, N_{Bo}	Hydrostatic to surface forces
Mach, N_{Ma}	Compressibility; or of oriented to random molecular motion

Thus, for those cases where the relative magnitude of a type of force is small, the effect of that dimensionless group which measures that force can be neglected.

B. Condensed Relationship

Since compressibility effects are significant only for high pressure pneumatic atomization and hydrostatic effects are significant only with very large drops, one may usually neglect the effects of N_{Ma} and N_{Fr}. Thus, for convenience, Equation A-2 may be written in the following identical alternative forms:

$$D_{xx}/D = k/N_{Re}^{\alpha}N_{Ca}^{\beta} = k/N_{Re}^{\alpha-\beta}N_{We}^{\beta} = k/N_{Re}^{\alpha+\beta}N_{Oh}^{\beta} \quad . \qquad \text{(A-15)}$$

This assumes that the role of Reynolds, Weber, capillary, or Ohnesorge numbers can be approximated by simple power functions. The "constant" k will include the effect of all the other terms of Equation A-2.

If we assume that (1) the effects of hydrostatic head (Froude number) and compressibility (Mach number) are negligible, (2) the effect of gas properties is small, and (3) the atomization is controlled by the relative velocity between gas and liquid rather than by the absolute velocity of either phase, then k would be expected to approach constancy at low liquid loadings provided the Reynolds and Weber numbers are expressed in terms of relative gas velocity and liquid properties. This suggests that a simplified means for comparing data may be: for simple stationary hydraulic atomizers discharging into stationary gas,

$$D_{xx}/D_j = k/N_{Re_{j,j}}^{\alpha-\beta} N_{We_{j,j}}^{\beta} \quad ; \tag{A-16}$$

for hydraulic and pneumatic atomizers in general,

$$D_{xx}/D_j = k/N_{Re_{j,r}}^{\alpha-\beta} N_{We_{j,r}}^{\beta} \tag{A-17}$$

for spinning disk atomizers,

$$D_{xx}/D_d = k/N_{Re_{j,d}}^{\alpha-\beta} N_{We_{j,d}}^{\beta} \quad . \tag{A-18}$$

This is essentially the format adopted by Mugele (1960).

C. Conversions

Assume that there is available a relationship of the form

$$D_{xx} = K_{xy} D^{n_D} u^{n_u} \rho^{n_\rho} \mu^{n_\mu} \sigma^{n_\sigma} \quad , \tag{A-19}$$

which is to be converted into the form of Equation A-15 or

$$(D_{xx}/D) = k/N_{Re}^{\alpha-\beta} N_{We}^{\beta} \quad . \tag{A-15}$$

By combining Equations A-15 and A-19,

$$k = K_{xy} D^{n_D+\alpha-1} u^{n_u+\alpha+\beta} \rho^{n_\rho+\alpha} \mu^{n_\mu-\alpha+\beta} \sigma^{n_\sigma-\beta} \quad . \tag{A-20}$$

The conversion can be made in several ways depending on which *two* terms are to be excluded from k. It is desirable to include those variables that have the most influence on fineness of atomization with N_{Re} or N_{We}, and, therefore, to exclude them from k. However, to logically justify exclusion of a variable from k, the investigator must have studied that variable and its effect on atomization to a significant extent. In most investigations the items most widely varied are nozzle size (D) and velocity (u).

Table A-I gives the factors α, β, and k corresponding to all the possible bases for converting from Equation A-19 to Equation A-15. In giving these conversions, the specific exponents refer only to the exponents on those terms which appear in the desired format of N_{Re} or N_{We} (*i.e.*, D_j and u_r if $N_{Re_{j,r}}$ is desired; D_j and u_j, if $N_{Re_{j,j}}$ is desired, etc.). Similar variables having different subscripts from those used to define N_{Re} or N_{We} are grouped together with their exponents as part of K_{xy}.

Table A-1

CONVERSION RELATIONSHIPS

TO OBTAIN $(D_{xx}/D) = k/N_{Re}^{\alpha-\beta}N_{We}^{\beta}$ FROM $D_{xx} = K_{xy}\,D^{n_D}u^{n_u}\rho^{n_\rho}\mu^{n_\mu}\sigma^{n_\sigma}$

CONTROLLING TERMS (Assumed)	α	β	$k = K_{xy}D^{n'_D}u^{n'_u}\rho^{n'_\rho}\mu^{n'_\mu}\sigma^{n'_\sigma}$				
			n'_D	n'_u	n'_ρ	n'_μ	n'_σ
D and u	$1 - n_D$	$n_D - n_u - 1$	0	0	$n_\rho - n_D + 1$	$n_\mu + 2n_D - n_u - 2$	$n_\sigma - n_D + n_u + 1$
D and ρ (possible only if $n_D = n_\rho$)	$1 - n_D$ or $-n_\rho$	indeterminate	0	$n_u - n_\rho + \beta$	0	$n_\mu + n_\rho + \beta$	$n_\sigma - \beta$
D and μ	$1 - n_D$	$1 - n_D - n_\mu$	0	$n_u - 2n_D - n_\mu + 2$	$n_\rho - n_D + 1$	0	$n_\sigma + n_D + n_\mu - 1$
D and σ	$1 - n_D$	n_σ	0	$n_u - n_D + n_\sigma + 1$	$n_\rho - n_D + 1$	$n_\mu + n_D + n_\sigma - 1$	0
u and ρ	$-n_\rho$	$-n_u + n_\rho$	$n_D - n_\rho - 1$	0	0	$n_\mu - n_u + 2n_\rho$	$n_\sigma + n_u - n_\rho$
u and μ	$(1/2)(n_\mu - n_u)$	$-(1/2)(n_\mu + n_u)$	$n_D + (1/2)(n_\mu - n_u) - 1$	0	$n_\rho + (1/2)(n_\mu - n_u)$	0	$n_\sigma + (1/2)(n_\mu + n_u)$
u and σ	$-(n_u + n_\sigma)$	n_σ	$n_D - n_u - n_\sigma - 1$	0	$n_\rho - n_u - n_\sigma$	$n_\mu + n_u + 2n_\sigma$	0
ρ and μ	$-n_\rho$	$-(n_\rho + n_\mu)$	$n_D - n_\rho - 1$	$n_u - 2n_\rho - n_\mu$	0	0	$n_\sigma + n_\rho + n_\mu$
ρ and σ	$-n_\rho$	n_σ	$n_D - n_\rho - 1$	$n_u - n_\rho + n_\sigma$	0	$n_\mu + n_\rho + n_\sigma$	0
μ and σ	$n_\mu + n_\sigma$	n_σ	$n_D + n_\mu + n_\sigma - 1$	$n_u + n_\mu + 2n_\sigma$	$n_\rho + n_\mu + n_\sigma$	0	0

APPENDIX B

BIBLIOGRAPHY ON ATOMIZATION

A. <u>Basis of Survey</u>

This bibliographic survey was undertaken to reveal information on atomization processes relevant to dissemination of chemical warfare agents. The survey was conducted in two phases: (a) a primary survey covering open literature and government report literature appearing between January 1950 and August 31, 1965, and (b) a supplementary survey of the open and government report literature appearing between September 1, 1965 and December 31, 1966. The primary survey includes some additional references appearing before 1950 and after September 1965 which were found as various articles were reviewed.

The reference sources consulted for both the primary and the supplementary survey are summarized in Table B-I. In addition, other sources were also consulted, including Stanford Research Institute files and the personal research files of staff scientists.

Table B-II presents a summary of the references in the primary survey classified by subject matter. The subject classification has been derived by review of the abstract (or title, when the abstract was not available). The subject classification in some cases may be erroneous or incomplete because of ambiguity of the abstract. The subject areas indicated are largely self explanatory. "Impingement-Hydraulic Atomization Techniques" includes jets impinging on each other, on a deflector, or on other solid surfaces. Stationary centrifugal or swirl nozzles (*i.e.*, fixed hydraulic nozzles with a tangential entry) are included under "Spray-Hydraulic Atomization Techniques." "External Vibrations" includes all techniques using externally applied vibrations, such as those produced by mechanically vibrated reeds or nozzles, solid state vibrators, or sonic or shock waves.

Detailed reference data follow Table B-II. The references are listed alphabetically by the last name of the first author, with the most recent article of that author given first. Where available, the reference is followed by an abstract, with the abstract source indicated by code at the end of the abstract. This code is identified in Table B-I and is the abbreviation given in the first column. When the abstract was by the author, the word "A[illegible] s indicated as the abstract source.

The following i[illegible] uals or organizations are extended special thanks for their permission to include their copyrighted materials.

Prof. K. J. DeJuhasz ("Spray Literature Abstracts")

Academic Press (J. Coll. Sci.)

American Institute of Physics (J. Chem. Phys., Rev. Sci. Instr., J. Appl. Phys., Soviet Phys.-Tech. Phys.)

American Physical Society (Phys. Rev.)

American Society of Mech. Engrs. (Applied Mech. Rev.)

Franklin Institute (J. Franklin Inst.)

Institute of Electrical Engineers (Physics Abstracts)

Pergamon Press (Chem. Eng. Sci.)

The Combustion Institute (Symposia on Combustion)

The American Chemical Society refused to grant permission to reproduce abstracts from any of their journals or from Chemical Abstracts, and the abstracts from these were omitted. Fortunately, there were only about 60 references from ACS abstracting sources for which abstracts could not be located elsewhere; the Chemical Abstract reference number has been indicated in those cases.

Table B-I

ABSTRACT SOURCES REVIEWED

ABSTRACT SOURCE [Abbreviation Used]	ISSUES REVIEWED	SUBJECT HEADINGS CHECKED	
International Aerospace Abstracts (Issued by AIAA) [A-Year-Abstract No., Issue No.-Section No.]	Jan. 1962 - Dec. 31, 1966	Aerosol Atomization Drops Electrostatics	Propulsion Fog Mist Spray
Applied Mechanics Reviews (Issued by ASME) [AMR-Vol. No.-Abstract No.]	Jan. 1950 - Dec. 1966	Entire Microreviews Section of Each Issue Aerosols Atomization Atomizers	Combustion - fuel jets Combustion - liquid drops Drops Jets - incompressible fl[illegible] Sprays
Battelle Technical Review (Issued by Battelle Memorial Institute) [BMI-Vol. No.-Abstract No.]	Jan. 1952 - Dec. 1966	Aerosol Atomization Drops Drying Apparatus	Flow Jets Sprays Turbulence
Chemical Abstracts (Issued by ACS) [CA-Vol. No.-Abstract No.]	Jan. 1950 - Dec. 28, 1966	Atomization Atomizers Colloids - Aerosols Drops Drying Apparatus, Spray Dust	Fog Insecticides Mists Particles Sprays
Dissertation Abstracts [DA-Vol. No.-Page No.]	Abstracts were taken from this source after reference was obtained from other sources	No subject index	
"Spray Literature Abstracts" (Vol. I), compiled and edited by K. J. DeJuhasz (Published by ASME, 1959) [de J I-Page No.]	Entire Volume	Each entry was checked	
"Spray Literature Abstracts" (Vol. II), compiled and edited by K. J. DeJuhasz (Published by ASME, 1964) [de J II-Page No.]	Entire Volume	Each entry was checked	
Scientific and Technical Aerospace Reports (STAR) (Issued by NASA) [N-Year-Abstract No., Issue No.-Section No.]	Jan. 8, 1963 - Dec. 31, 1966	Aerosol Atomization Charged Particles Drops Electrostatic Propulsion	Fog Jets Sprays Turbulence
Physics Abstracts: Science Abstracts Section A (Issued by the Institute of Physics) [PA-Vol. No.-Abstract No.]	Jan. 1950 - Dec. 1966	Aerosols Atomization Combustion Drops Flow Hydrodynamics	Impact Jets Liquid Oscillations Sprays Turbulence

Table B-I (Concluded)

ABSTRACT SOURCE [Abbreviation Used]	ISSUES REVIEWED	SUBJECT HEADINGS CHECKED	
Technical Translations*† (issued by the Dept. of Commerce, OTS) [T-Vol. No.-Page No.]	Jan. 1958 - Dec. 31, 1966	Aerosols Atomization Combustion	Drops Jets Sprays
Technical Abstract Bulletin (issued by the Dept. of Commerce, CFSTI) [TAB-Year-Issue No.]		This bulletin contains abstracts of ASTIA documents. The abstract was obtained from this bulletin in those cases where an AD-number reference was available from other sources.	
Putnam, A. A., *et al.*, "Injection and Combustion of Liquid Fuels," WADC Tech. Rept. 56-344, 1957		All references at the end of Chapters 1-4 were checked and some 60 of the 237 references were added to the bibliography.	

* In the "Technical Translations" abstracts the following abbreviations are used to indicate the source of the translation:

ATS
Associated Technical Services, Inc.
P.O. Box 271
East Orange, New Jersey 07017

CFSTI
Clearinghouse for Federal Scientific & Technical Information
(Formerly Office of Technical Services)
Port Royal & Braddock Roads
Springfield, Virginia 22151
(Also available through Dept. of Commerce Field Offices)

CNRS
Centre National de la Recherche Scientifique
Centre de Documentation
15 Quai Anatole France
Paris 7, France

ETC
European Translations Centre
Doelenstraat 101, Delft,
The Netherlands

LC
Photoduplication Service
Publication Board Project
Library of Congress
Washington, D.C. 20540

OTS
See CFSTI

SLA
SLA Translations Center
The John Crerar Library
35 West 33rd Street
Chicago, Illinois 60616

TTIS
Translation and Technical Information Services
32 Manaton Road
London, S.E. 15, England

† The following names were checked against the author index in "Technical Translations" for the period January 1958-December 15, 1966. These names represent workers in the fields of atomization and spraying who publish in languages other than English.

Bezemer, C.	Diciakin, U. F.	Klein, E.	Semerchan, A. A.
Blinov, V. I.	Engelhard, H.	Kling, R.	Stange, K.
Blokh, A. G.	Esche, R.	Kranz, J.	Troesch, H. A.
Boucher, R.	Euteneuer, G. A.	Kuberjev, M. N.	Ueyama, K.
Buckhman, S. V.	Gebhardt, H.	Lyshevskii, A. S.	Valdenazzi, L.
Debeauvais, F.	Golovkov, L. G.	Popov, M.	Vereshchagin, L. F.
Degtev, O. N.	Il'yashenko, S. M.	Popov, V. F.	Volynskii, M. S.
Deryagin, B. V.	Kawada, M.	Schreiner, K.	Zagar, L.
Diamant, W.	Khokhlov, S. F.	Schwarz, N. A.	Zawidzki, T. W.

These names were also checked in "Translation Monthly" for the period Jan. 1955 - Dec. 1957. "Translation Monthly" is the predecessor of "Technical Translations" and does not have a subject index.

Table B-II

SUBJECT CLASSIFICATION OF REFERENCES
IN PRIMARY SURVEY

AUTHOR	YEAR	TITLE OR SUBJECT	Atomization Techniques										Drop Size				
				Hydraulic													
			Basic Principles	Spray	Impingement	Pneumatic	Rotational	Electrostatic	External Vibration	Flashing or Thermal	Explosive	Miscellaneous	Measurement Techniques	Distribution Data	Spray Drying	Other Application Areas	Liquid Properties and Property Measurement
Anon.	1964	Process for Handling Sulphur														•	
Anon.	1960	Soviet R&D in Insecticides and Application		•												•	
Anon.	1950	Disintegration of a Water Droplet	•														
Anon.	1949	Fuel Injection in Diesel Engines	•														
Anon.	1929	Airless Injection in Diesel Engines	•	•													
Abdyldaev	1960	Three Dimensional Thin-Layer Jet Flow														•	
Abramovich	1960	Theory of Turbulent Jet														•	
Abramovich	1944	Theory of Centrifugal Nozzle		•													
Adler	1950	Atomization of Water with Spinning Disks (Thesis)					•										
Adler, et al.	19[illegible]	Scanning Device for Size Distribution of Sprays											•	•			
Adler, Marshall	1951	Spinning Disc Atomizers, I					•										
Adler, Marshall	1951	Spinning Disc Atomizers, II					•										
Aerojet-General Corp.	1962	Aerodynamic Breakup	•														
Ailam, Gallily	1962	Stability of an Electrically Charged Drop						•									
Akimenko	1960	Outflow of Water Atomizers		•													
Alterman	1961	Capillary Instability of Liquid Jet	•														
Amer. Soc. for Testing Mat'ls.	1958	Symposium on Particle Size Measurement											•				
Amsden	1960	Production of Uniform Droplets														•	
Anson	1953	Influence of Atomization on Combustion				•											
Antonevich	1959	Ultrasonic Atomization of Liquids							•								
Arni	1959	Production Movement, Evaporation of Sprays		•										•	•		
Asatur, Geronter	1957	Study of Non-Submerged Jets	•	•													
Asset	1959	Microburet for Prod. Uniform Droplets														•	
Asset, Bales	1951	Hydrauli Jets at Low Re and Constant We		•													
Atkinson, Miller	1965	Production of Uniform Drops										•					
Balje, Larson	1949	Mechanism of Jet Disentegration	•	•													
Banerjee, Rao	1962	Entrainment of Water Drops	•	•		•											
Baron	1947	Atomization of Liquid Jets and Droplets	•	•													
Baron, Alexander	1951	Momentum, Mass, Heat Transfer in Free Jets														•	
Barret	1956	Catoodic Atomization of Electrolytes						•									
Barret	1954	Cathodic Atomization of Fused Electrolytes						•									
Barret	1952	Dispersion of Solutions by Anodic Spark						•									
Barret	1952	Mechanical Effects in Electrolysis						•									
Barret	1950	Measurement of Flame Temperatures						•									
Beardsley	1927	NACA Fuel Spray Photography Apparatus												•		•	
Beardsley	1927	Oil Sprays for Fuel-Injection Engines														•	
Benson, et al.	1960	Drop Size Distribution of Liquid Sprays												•	•		
Beatly, et al.	1953	Method of Observing Drop Size												•			
Berg	1962	Aerodynamic Breakup				•											
Bergsde	1949	Spray Drying					•								•		
Bergwerk	1959	Flow Pattern in Diesel Nozzle Spray		•													
Bornelius	1961	Apparatus for Study of Atomization	•				•										
Boto, Neilson	1960	Drop Size Measuring Methods												•	•		
Bots, Petersohn	1932	Application of Theory of Free Jets		•												•	
Bevens	1949	Math Expressions for Drop Size Distribution													•		
Bessmer, Schwarts	1956	New Equation for Size Distribution													•		
Bigg	1955	Atomization of Water by Air Blast				•											
Biles	1949	Analysis of Short Length Liquid Sprays	•														
Bimark, Hans	1950	Quick Method for Measuring Drop Size															

AUTHOR	YEAR	TITLE OR SUBJECT	Atomization Techniques: Basic Principles	Atomization Techniques: Hydraulic: Spray	Atomization Techniques: Hydraulic: Impingement	Atomization Techniques: Pneumatic	Atomization Techniques: Rotational	Atomization Techniques: Electrostatic	Atomization Techniques: External Vibration	Atomization Techniques: Flashing or Thermal	Atomization Techniques: Explosive	Atomization Techniques: Miscellaneous	Drop Size: Measurement Techniques	Drop Size: Distribution Data	Spray Drying	Other Application Areas	Liquid Properties and Property Measurement
Binark, Ranz	1958	Simple Method for Measuring Drop Size											●				
Binark, Ranz	1958	Air Flows in Fuel Sprays														●	
Binnie	1951	Theory of Waves on Core of Swirling Liquid		●													
Binnie, Harris	1950	Swirling Liquid Flow Through a Nozzle		●													
Bird	1926	Oil Jets and Their Ignition		●												●	
Bisa et al.	1954	Atomization of Liquids by Ultrasonics							●								
Bitron	1955	Atomization by Supersonic Air Jets				●											
Bittker	1964	Effect of Ambient Air Velocity on Atomization			●	●											
Blanchard	1954	Prod. of 1 to 500 Micron Homogeneous Water Drops														●	
Blanchard	1950	Behavior of Water Drops at Terminal Velocity	●														
Blinov	1931	Properties of Mechanically Atomized Water		●									●	●			
Blokh, Kichkina	1958	Atomization by Centrifugal Sprayers					●										
Bohr	1909	Surface Tension by Method of Jet Vibration															●
Bolt, Boyle	1956	Combustion of Liquid Fuel Spray					●							●			
Bonch	1960	Pulsating Aerosol Generators														●	
Bond	1935	Surface Tension of a Water Sheet															●
Borisenko	1953	Influence of Turbulence on Atomization	●	●													
Borodin et al.	1964	Breakup of Liquid Jet	●			●											
Borodin, Dityakin	1951	Unstable Capillary Waves	●														
Bose et al.	1960	Glass Atomizer for Paper Chromatography														●	
Boshoff	1952	Characteristics of Spinning-Disc Sprayer					●							●			
Boucher	1952	Influence of Air/Liquid Ratio on Atomization				●											
Boussinesq	1913	Theory of Reconverging Liquid Sheets	●		●												
Boussinesq	1869	Theory of Form of Liquid Jet	●		●												
Bowen, Joyce	1948	Effects of Parameters on Particle Size		●									●	●			
Bowen, Joyce	1947	Swirl Pressure Jet Atomizers		●													
Brackenridge	1960	Oscillations of Liquid Jet I	●														
Brackenridge, Nyborg	1961	Oscillations of Liquid Jet II	●														
Brown, E. N.	1961	Rotating Bowl for Prod. of Uniform Drops					●										
Brown, H. E. and E. C. Young	1950	Characteristics of Low Pressure, Disc-Type Nozzles				●											
Brown, R. E. and K. L. Leonard	1964	Describing Droplet-Size Distributions				●								●			
Brown, R. and J. L. York	1962	Sprays by Flashing Liquid Jets								●							
Browning	1964	High Energy Atomizer for Fire Extinguishment															
		(U.S. Patent)														●	
Browning	1958	Prod. & Measurement of Single Drops, Sprays		●	●	●	●						●	●			
Brun, Levine et al.	1951	Instrument Employing Coronal Discharge											●				
Brun, Lewis et al.	1955	Impingement of Droplets on a Cylinder											●				
Brun, Mergler	1953	Impingement of Water Droplets on a Cylinder											●				
Bruniak, Magyar	1952	Nozzles for the Atomization of Liquids		●													
Buchmann	1955	Exper. Investigation of Drop Disintegration				●							●				
Buckhman, Chernov	1957	Binary-Phase Free Jets				●											
Buki	1962	Heat Transfer in Liquid Atomizers		●												●	
Burdette	1938	Production of Air-Floated Oil Particles														●	
Burton, E. F. and W. B. Wiegand	1912	Effect of Electricity in Streams of Water Drops						●									
Burton, E. J. and J. R. Joyce	1957	Size of Droplets from Convergent-Divergent Nozzles				●							●	●			
Byutner	1964	Dispersion of Particles														●	
Cadle	1965	Particle Size, Theory and Applications											●				
Cadle	1955	Particle Size Determination											●				
Cahn	1962	Stability of Charged Droplets						●									
Carson	1964	Electrical Spraying of Liquid Particles						●									
Castleman	1932	Mechanism of Solid Injection Atomization	●	●													
Castleman	1931	Mechanism of Atomization of Liquids	●	●		●											

AUTHOR	YEAR	TITLE OR SUBJECT	Atomization Techniques										Drop Size				
			Basic Principles	Hydraulic: Spray	Hydraulic: Impingement	Pneumatic	Rotational	Electrostatic	External Vibration	Flashing or Thermal	Explosive	Miscellaneous	Measurement Techniques	Distribution Data	Spray Drying	Other Application Areas	Liquid Properties and Property Measurement
Castleman	1924	Influence of Instability on Liquid Columns	•														
Chadeyron et al.	1957	Method of Observation of Atomized Jets											•				
Chaikin, Wilbur	1960	Generator for Aerosols														•	
Chamberlin et al.	55	Airplane Spray-Deposit Patterns														•	
Chandrasekhar	1965	Stability of a Rotating Liquid Drop	•														
Chem. Res. and Dev. Labs	1958	Spray Dissemination of Agents, I	•										•				
Chem. Res. and Dev. Labs	1958	Spray Dissemination of Agents, II	•										•				
Chen, Davis	1964	Disintegration of a Turbulent Jet		•									•	•			
Cheng, Cordero	1963	Droplet Formulation from Rotating Cylinder					•										
Chevalerias, Kling	1957	Atomization and Combustion in High-Speed Air Stream				•							•				
Chih-En	1945	Charge Produced by Spraying Liquids						•									
Choudhury	1956	Size Distribution of Drops from Centrifugal Nozzles		•									•	•			
Cisinsky, Kolousek	1959	Ultra-Centrifuge as Aerosol Generator					•										
Clare, Radcliffe	1954	Air-Blast Atomizer				•								•			
Clutter	1953	Aeroproject's Ultrasonic Generator							•								
Cohen, E.	1964	Charged Colloid Generation						•									
Cohen, L.	1958	Spray Dissemination of Thickened Liquids		•													•
Cohen, N. and M. Webb	1962	Evaluation of Swirl Atomizers by Light Scattering		•													
Colbourn, Heath	1950	Swirl Atomizer Sprays in Partial Vacuum		•													
Collacott	1959	Impact of Drops-Photography of Disintegration											•				
Comings	1947	Atomization and Mixing of Fluid Streams		•		•								•			
Comings et al.	1948	High Velocity Vaporizers								•							
Consiglio, Sliepcevich	1957	Effect of Liquid Properties on Spray Surface Area		•									•	•			
Corcoran	1960	Aerosol Distributions and Breakup of Droplets	•										•				
Corcoran	1958	Aerodynamic Breakup of Droplets	•										•	•			
Cosby	1950	Formation and Stability of Disperse Systems														•	
Courshee	1954	Testing a Spray Deposit Analyzer											•				
Courshee, Byass	1953	Study of Methods of Measuring Spray Drops											•				
Crane, Birch, McCormack	1964	Eff. of Mech. Vibration on Water Jet Breakup	•						•								
Crawford	1955	Prod. of Spray by Magnetostriction Transducers							•								
Crowe et al.	1963	Drag Coefficients of Accelerating Particles														•	
Culp	1964	Electrically Atomizing Volatile Liquids						•									
Culverwell	1955	Binary Component Spray Vaporization														•	
Culverwell et al.	1956	Binary Component Spray Vaporization												•		•	
Dalla Valle	1947	Micromeritics (Book)											•			•	
Darmois	1954	Cathodic Atomization of Solutions						•									
Darnell	1953	Atomization by Centrifugal Pressure Nozzles (Thesis)		•													
Dautrebande	1958	Studies on Aerosols											•			•	
Dautrebande	1958	Apparatus for Generation of Aerosols														•	
Davies, C. N.	1964	Recent Advances in Aerosol Research (Book)														•	
Davies, D. A., Venn, Willis	1965	Atomizer for Spectroscopy														•	
Davis	1951	Vibratory Apparatus for Uniform Drops							•								
Davis	1949	Method for Recording Size of Spray Drops											•				
Debeauvais	1957	Disintegration of Liquid Jets in Moving Air				•							•				
Debeauvais	1957	Forced Atomization in a Carburetor				•							•				
Debye, Daen	1959	Stability of Nonviscous Jets	•														•
De Corso	1960	Effect of Pressure on Spray Drop Size		•													
De Corso	1959	Effect of Pressure on Spray Drop Size		•													
De Corso, Kemeny	1956	Effect of Pressure on Spray Angle		•													
Defay, Hommelen	1958	Bibliography on Surface Tension Measuring Methods															•
Degtev	1956	Atomization of Viscous Liquids				•											
Degtev	1956	Deformation of Drops				•											

AUTHOR	YEAR	TITLE OR SUBJECT	Atomization Techniques										Drop Size				
				Hy-draulic													
			Basic Principles	Spray	Impingement	Pneumatic	Rotational	Electrostatic	External Vibration	Flashing or Thermal	Explosive	Miscellaneous	Measurement Techniques	Distribution Data	Spray Drying	Other Application Areas	Liquid Properties and Property Measurement
DeJuhasz	1964	Spray Literature Abstracts, Vol II														●	
DeJuhasz et al.	1959	Spray Literature Abstracts, Vol I														●	
DeJuhasz, Zahn, Schweitzer	1932	Formation and Dispersion of Oil Spra s		●									●				
Delavan	1958	Spray Droplet Technology											●	●			
Dempster, Sodha	1957	Secondary Atomization of Droplets														●	
de Ong, Peer, Fancher	1950	Generator for Dry Aerosols														●	
Dery.gin, Vlasenko	1948	Measurement of Concentration of Aerosols											●				
Diamant	1961	Photomicrographic Study of Atomization		●									●				
Dickerson, Schumann	1965	Rate of Aerodynamic Atomization				●											
Dimmick	1959	Jet Disperser for Powders														●	
Dimmick, Hatch, Ng	1958	Particle-Sizing Method for Aerosols											●				
Dimmock	1951	Prod. of Streams of Identical Droplets							●								
Dimmock	1950	Prod. of Uniform Droplets							●								
Dityakin	1954	Stability and Disintegration of Elliptic Jets	●	●													
Dityakin, Britnera	1959	Drop Size Measurements with Dimensionless Criteria		●													
Dityakin, Iagodkin	1957	Influence of Parameters on Disintegration of Jets		●													
Dobbins, Crocco, Glassman	1963	Mean Particle Size of Sprays by Diffraction Scattering											●				
Doble	1947	Design of Centrifugal Spray Nozzles		●													
Doble	1945	Design of Spray Nozzles		●									●				
Doble, Halton	1947	Application of Cyclone Theories to Nozzles		●													
Dodd	1960	Disintegration of Water Drops by Shock Waves	●			●											
Dodd	1960	Disintegration of Water Drops in Air Streams	●			●											
Dodd	1960	Disintegration of Water Drops in an Air Stream	●						●								
Dodge, Hagerty, York	1950	Continuous Fuel Sprays											●				
Dodu	1964	Dispersion of High Speed Liquid Jets		●													
Dodu	1959	Influence of Weber and Reynolds Number on Dispersion															
		of Jets		●													
Dombrowski et al.	1957	Disintegration of Thin Sheets of Fluid		●													
Dombrowski, Fraser	1954	Disintegration of Liquid Sheets		●									●				
Dombrowski, Fraser, Peck	1955	Double-Flash System for Photography		●									●				
Dombrowski, Hasson, Ward	1960	Liquid Flow through Fan Spray Nozzles		●													
Dombrowski, Hooper	1964	Sprays Formed by Impinging Jets			●												
Dombrowski, Hooper	1962	Performance of Impinging Jet Atomizer			●												
Donnelly, Wehl	1950	Progress on Spray Research														●	
Dorman	1952	Atomization in a Flat Spray		●									●				
Doumas, Laster	1953	Liquid Film Properties for Centrif. Spray Nozzles		●													
Doyle, A.W. et al.	1962	New Means of Fuel Atomization						●	●								
Doyle, G. J. P.	1956	Sonic Determination of Aerosol Size											●				
Drazin	1961	Discontinuous Velocity Profiles	●													●	
Drazin	1960	Stability of a Broken Line Jet in Magnetic Field	●														
Drozin	1955	Electrical Dispersion of Liquids							●								
Druett, May	1954	Prod. of Individual Sized Droplets						●	●								
Dubrow	1952	Statistical Description of Particle Size												●			
Duffie, Marshall	1953	Properties of Spray Dried Materials		●									●		●		
Dunne, Cassen	1956	Instability of a Liquid Jet							●				●				
Dunne, Cassen	1954	Supersonic Liquid Jets				●											
Dunskii	1956	Coagulation During Atomization				●										●	
Dunskii	1956	Coagulation in Mechanical Dispersion				●										●	
Dunskii, Kitaer	1958	Electrostatic Spraying						●									
Dunskii et al.	1956	Thermo-Mechanical Fog Formation														●	
Dyatlov, Khokalov	1960	Theory of Disc Sprayers					●										

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Echols, Young	1963	Portable Aerosol Generators				•											
Eichborn	1953	Analysis of Aerosols and Gaseous Suspensions		•	•	•		•	•				•				
Eichler	1961	Apparatus for Producing H_2SO_4 Fog														•	
Eisbinder	1955	Theory of Particle Impaction											•				
Eisenklam	1961	Atomization of Fuel for Combustion		•		•	•						•	•		•	
Eisenklam et al.	1959	Drop Formation from Liquid Sheets	•														
Eisenklam, Hooper	1958	Flow Characteristics of Liquid Jets														•	
Eknadiosyants	1963	Kinetics of Ultrasonic Fog Formation							•								
Ellis	1960	Atomization of Liquids														•	
Ellis	1950	Flow through Swirl Atomizers		•													
Engel	1958	Fragmentation of Water Drops							•								
Engelhard	1960	Basic Research on Aerosols - 1930-1954											•			•	
Epstein	1947	Math Description of Breakage Mechanisms	•											•			
Ericksen	1952	Thin Liquid Jets	•														
Esche	1955	Ultrasonic Space Aerosols							•					•			
Eutenauer	1957	Drop Size and Throw Distance of Jet Sprays		•										•			
Eutenauer	1956	Influence of Surface Tension on Liquid Jets		•													
Falk	1947	Atomization by Opposed Jets			•												
Fedoseyev	1958	Atomization of Superheated Fluid								•							
Ferrie, Manson	1952	Micrographs of Atomized Jets												•			
Filistaev et al.	1960	Spray Drying of Ceramic Suspensions													•		
Fisher	1956	Particle Size Distribution Measurement											•				
Fogler, Kleinschmidt	1938	Spray Drying													•		
Foster, Heidmann	1960	Water Spray by Impinging Jets			•									•			
Fraser	1961	Liquid Atomization														•	
Fraser	1957	Functions of the Spray Nozzle														•	
Fraser	1956	Liquid Fuel Atomization														•	
Fraser	1955	High Speed Photography											•				
Fraser, Dombrowski	1956	Photographic Technique in Fluid Kinetics											•				
Fraser, Dombrowski	1955	High Speed Photography				•							•				
Fraser et al.	1954	Vibration as a Cause of Disintegration		•													
Fraser et al.	1963	Characteristics of Rotary Cup Blast Atomizers					•										
Fraser et al.	1963	Atomization of a Liquid Sheet by Impinging Air				•											
Fraser et al.	1963	Filming of Liquids by Spinning Cups					•										
Fraser et al.	1963	Uniform Liquid Sheets from Spinning Cups					•										
Fraser et al.	1963	Disintegration of Liquid Sheets in Air Streams	•				•										
Fraser, Eisenklam	1956	Liquid Atomization and Drop Size		•	•	•	•							•			
Fraser, Eisenklam	1953	Performance of Atomizers for Liquids	•											•			
Fraser et al.	1957	Liquid Atomization in Chem Engineering		•		•	•										
Fraser et al.	1963	Drop Formation from Liquid Sheets				•											
Friedman et al.	1953	Centrifugal Disc Atomization					•										
Fritsch	1960	Aerodynamics of Oil Burners														•	
Fruengel	1961	Methods of Photographic Recording											•				
Fry, Thomas, Smart	1950	Fire-Fighting Sprays by Impinging Jets			•												
Fuchs	1964	Mechanics of Aerosols											•				
Fuchs	1949	Droplet Size in Oil Fogs														•	
Fuhs	1958	Spray Formation and Breakup	•	•		•								•			
Gage	1963	Controlled Fluid Feed Atomizer														•	

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Gellily, LaMer	1958	Behavior of Liquid Droplets Impinging on Surface			•								•				
Gens, Kusnetsov	1965	Design of Towers with Centrifugal Atomizers					•							•		•	
Garner, Ellis, Lacey	1954	Size Distribution & Entrainment of Droplets		•									•				
Garner, Henny	1953	Behavior of Spray at High Altitude Conditions		•													
Garner, Nissan, Wood	1950	Rheological Behavior of Elasto-Viscous Systems	•	•									•			•	
Gaskins, Philipott	1958	Breakup of Viscoelastic Jets		•													•
Gavis	1959	Propagation of Waves on Jets	•													•	
Gebhardt	1959	Atomizati . with Swirl Nozzles. I, II		•													
Gebhardt	1958	Drop Sizes with Swirl Nozzle Atomization		•									•	•			
Gebhardt	1958	Atomization with Swirl Nozzles		•													
Geist	1952	Electronic Spray Analyzer											•				
Geist, York, Brown	1951	Electronic Spray Analyzer											•				
Gelalles	1930	Effect of Temperature on Spray Penetration and Dispersion		•													
Gelperin, Vil'nits	1955	Emission of Liquids from Openings														•	
Gershenzon, Eknadiosyants	1964	Atomization in a Ultrasonic Fountain							•								
Gessner	1935	Method of Drop Size Measurement											•				
Giffin	1952	Atomization of Fuel Sprays		•									•				
Giffen, Lamb	1953	Effect of Air Density on Spray Atomization		•									•				
Giffen, Massey	1951	Atomization with Swirl Atomizers		•									•				
Giffen, Massey	1950	Observation on Flow in Spray Nozzles		•													
Giffen, Muraszew	1953	Atomization of Liquid Fuels		•									•				
Giffen, Muraszew	1948	Atomization of Low-Pressure Fuel Sprays														•	
Giffen, Muraszew	1948	Measurement of Atomization in Fuel Sprays											•			•	
Giffen, Neale	1954	Effect of Gas Viscosity on Spray Atomization		•									•				
Gignoux, Anton, Shea	1964	Dev. of Charged Colloid Source for Electrostatic Propulsion						•									
Gillis, Kaufman	1962	Stability of Rotating Viscous Jet	•														
Gillis, Suh	1962	Stability of Rotating Liquid Column	•														
Gilman	1942	Photographic Method for Size Dist. of Sprays (Thesis)				•							•				
Glahn et al.	1955	Dye Tracer Technique											•				
Glendenning	1939	Oil Atomization by Small Pressure Nozzles		•													
Glonti	1958	Stability of Jets in Electric Field						•									
Golitzine	1954	Spraying of Liquids		•	•	•	•						•			•	
Golitzine	1951	Measuring Size of Water Droplets											•	•			
Golitzine et al.	1951	Spray Nozzles for Simulation of Cloud Conditions														•	
Golovin	1964	Breakdown of Droplets in Gas Stream	•														
Golovkov	1964	Size Distribution of Droplets		•													
Gontar	1959	Effect of Pressure on Size Distribution		•									•	•			
Goodger	1956	Fuel Spray Investigations														•	
Gorbatshev, Nikiforova	1935	Upper Stability Limit of Colliding Drops	•		•											•	
Gordon, G. D.	1959	Mechanism and Speed of Breakup of Drops	•	•													
Gordon, M. G.	1960	Cold Gas Atomization				•							•	•			
Gordon, M. G.	1960	Hot Gas Aerosolization								•							
Gordon, M. G.	1960	Atomization with Cold Gas				•											
Goren, Gavis,	1961	Wave Motion on Thin Capillary Jet	•														
Graf	1962	Breakup of Liquid by Elec. Charging						•									
Green	1953	Atomization of Liquids		•		•	•						•	•			
Green	1951	Problems in the Atomization of Liquids	•													•	
Green	1927	Average Particle Size											•				
Green, Lane	1957	Particulate Clouds (Book)		•	•	•	•		•				•			•	
Greenough	1960	Wax Atomizer				•							•	•			
Gretzinger	1956	Pneumatic Atomizers (Thesis)				•											
Gretzinger, Marshall	1961	Characteristics of Pneumatic Atomization				•											
Griffith	1943	Theory of Size Distribution in a Comminuted System												•			

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			Basic Principles	Hydraulic: Spray	Hydraulic: Impingement	Pneumatic	Rotational	Electrostatic	External Vibrations	Flashing or Thermal	Explosive	Miscellaneous	Measurement Techniques	Distribution Data	Spray Drying	Other Application Areas	Liquid Properties and Property Measurement
Grosvenor	1955	Atomization of Liquid Fuels by Natural Gas				•										•	
Gucker, Doyle	1956	Vibration of Droplets in Sonic Field	•						•								
Gunn	1965	Collision of Falling Water Drops			•											•	
Gurevich	1959	Instability of Jet Flows	•														
Gütter	1959	Centrifugal Atomizer for Fuels					•									•	
Gwyn, Crosby, Marshall	1965	Bias in Size Analysis by the Count Method											•	•			
Haas	1964	Stability of Droplets	•			•											
Hasse	1957	Fine Dispersion of Medications				•											
Haenlein	1931	Disruption of a Liquid Jet	•	•													
Hagerty, Shea	1955	Stability of Plane Fluid Sheets	•	•													
Hagerty, Yagle	1951	Rapid Spray Analyser		•													
Hagerty, Yagle, El-Sadan	1957	Design of Swirl Nozzles		•													
Hagerty et al.	[illegible]	Continuous Fuel Sprays		•													
Hamilton, Smith	1925	Colorimetric Method for Sprayed Lead Arsenate														•	
Hansell	1950	Jet Sprayer Actuated by Supersonic Waves							•								
Hansen	1955	Theory of Vibrating Jets							•								
Hanson, Domich, Adams	1963	Breakup of Drops by Air Blasts				•			•								
Harmon	1955	Equation for Mean Drop Size at High Speeds		•													
Harmon	1955	Drop Sizes from Low Speed Jets		•													
Harvey, Hermandorfer	1943	Design of Oil Atomizers		•		•											
Hasson, Mizrahi	1961	Drop Size from Fan Spray Nozzles		•									•	•			
Hasson, Peck	1964	Thickness of Sheet formed by Impinging Jets			•												
Hausser, Strobl	1924	Drop Size Measurement in Atomized Liquids											•	•			
Hawthorne	1943	Atomizer Research at MIT														•	
Heath, Radcliffe	1950	Air Blast Atomizer				•											
Hege	1964	Liquid Dispersion by Centrifugal Discs					•							•			
Heidmann	1960	Time Variation of Drop Size in Spray			•								•	•			
Heidmann, Foster	1961	Effect of Impingement Angle on Drop Size			•								•	•			
Heidmann, Humphrey	1952	Fluctuations in a Spray from Impinging Jets			•												
Heidmann, Humphrey	1951	Fluctuations in a Spray from Impinging Jets			•												
Heidmann et al.	1957	Sprays by Impinging Jets			•								•	•			
Heinrich, Dräger	1957	Centrifugal Atomizer for Liquids (German Patent)					•?										
Helmholtz	1868	Instability in Surface	•														
Hendricks	1963	Charged Particle Propulsion						•									
Hendricks	1962	Charged Droplet Experiments						•									
Hendricks	1959	Charged Droplet Experiments						•									
Hendricks et al.	1963	Electrically Sprayed Heavy Particles						•					•				
Hendricks, Schneider	1963	Stability of Conducting Droplet						•									
Hendrickson	1958	Bibliography on Aerosol Production														•	
Herring, Marshall	1955	Vaned-Disc Atomizers					•										
Herrmann	1961	Atomizers for Photometry														•	
Heubner	1925	Measurement of Droplet Size in Atomized Liquids											•				
Hidy	1965	Theory of Coagulation														•	
Hill	1950	Dependence of Surface Energy on Radius	•													•	•
Hinrichs	1963	Atomization of Water		•													
Hinze	1955	Hydrodynamic Mechanism of Splitting	•														
Hinze	1949	Deformations of Liquid Globules	•														
Hinze	1949	Critical Speeds and Sizes of Liquid Globules	•														
Hinze	1946	Disintegration of High Speed Jets		•													
Hinze, Milborn	1950	Atomization by Rotating Cup					•						•	•			
Hodgkinson	1950	Control by Surface Tension of a Conical Fluid Sheet Jet										•				•	

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				Hydraulic													
			Basic Principles	Spray	Impingement	Pneumatic	Rotational	Electrostatic	External Vibration	Flashing or Thermal	Explosive	Miscellaneous	Measurement Techniques	Distribution Data	Spray Drying	Other Application Areas	Liquid Properties and Property Measurement
Hogan	1963	Charge/Mass of Electrically Sprayed Particles						•									
Hogan, Hendricks	1965	Charge-Mass Ratio of Electrically Sprayed Liquid						•									
Hulfelder	1932	Atomization in Diesel Engines		•													
Holland	1956	Size Distribution Relationships												•			
Holroyd	1933	Atomization of Liquid Jets		•									•				
Hommelen	1956?	Measuring Surf. Tens. by Oscillating Jet															•
Hopkins	1946	Size Distribution of Droplets												•			
Horgan, Edwards	1961	Forces in Dielectric Fluids						•									
Houghton	1950	Spray Nozzles		•	•	•	•							•			
Hrubecky	1958	Atomization by Air Streams				•											
Hrubecky	1954	Air-Stream Atomization				•											
Hughes, Gilliland	1951	Mechanics of Drops														•	
Huss	1950	Airplane Spray Apparatus														•	
Hydro-Nitro Soc.	1949	Improvement of Bioclimatic Condition				•		•									
Il'yashenko	1960	Centrifugal Spray Burners I		•													
Il'yashenko	1960	Centrifugal Nozzles II		•													
Ingebo	1962	Atomization and Combustor Performance														•	
Ingebo	1961	Size Distribution of Ethanol Drops												•			
Ingebo	1958	Drop Size Distributions for Impinging Air Jet				•							•	•			
Ingebo	1956	Drag Coefficients for Accelerating Droplets														•	
Ingebo	1954	Vaporization Rates and Drag Coefficients														•	
Ingebo, Foster	1957	Drop-Size Distribution for Cross-Current Breakup				•											
Institute of Physics	1954	Physics of Particle Size Analysis (Symposium)											•	•			
Irani, Callas	1963	Particle Size: Measurement, Interpretation (Book)											•				
Isler, Thornton	1955	Atomization and Airplane Spray Patterns														•	
Ismailov, Tadzhibaev	1960	Distillation by Atomization														•?	
Ito	1932	On Hollow Spindle-Shaped Liquid Jet		•													
Ivanilov	1965	Behavior of Vortex Jet		•													
Isard, Cavers, Forsyth	1963	Liquid Drops by Discontinuous Injection														•	
Jaeger, Weber	1951	Spraying App. for Elec. Charged Aerosol															
		(Swiss Patent)						•									
Jarman	1957	Rotary Atomizers					•										
Jayaratne, Mason	1964	Coalescence and Bouncing of Drops			•												
Jenkins	1957	Shatter of Raindrops	•	•												•	
Jenkins, Booker, Sweed	1961	Impact of Drops on High Speed Moving Surface														•	
Joeck	1950	Atomization by Supersonic Sound (U.S. Patent)							•								
Johnson	1963	Production of Liquid Drops						•									
Jones, Straughn, Tarpley	1957	Aerosolization Unit (U.S. Patent)								•						•	
Joyce	1953	Atomizing Liquid Fuel		•	•	•	•										
Joyce	1949	Atomization of Liquid Fuel		•	•	•	•						•	•			
Joyce	1947	Fuel Atomizers for Gas Turbines		•													
Joyce	1946	Wax Method of Size Measurement											•	•			
Kawada	1939	Atomizer with Impinging Jets			•									•			
Keats	1961	Aerosols (U.S. Patent)									•						
Keller, Kolodner	1954	Instability of Liquid Surfaces	•	•													
Keller, Weitz	1957	Theory of Thin Jets	•														

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Kerkner, Cox, Schoenberg	1955	Max. Particle Size in Aerosols											•			•	
Kethley et al.	1957	Air-borne Microörganisms in Aerosol Studies											•				
Khokhlov	1960	Hydrodynamics in a Centrifugal Column					•									•	
Kim	1959	Drop-Size Distributions from Pneumatic Atomizers				•											
Kinoshita, Uehiyama	1932	Size of Fog Droplets											•				
Kirchhoff	1869	Theory of Free Liquid Jets	•														
Kivnick	1952	Coalescence of Droplets in a Turbulent Jet			•											•	
Klein	1958	Drop Size Distribution in a Spray				•							•	•			
Kleinschmidt	1950	Dispersion of Liquid Droplets														•	
Kling	1960	Appearance of Combustion in a Turbo-Jet														•	
Kling	1958	Atomization of Liquid Fuels					•						•				
Kling	1957	Microphotography of Fuel Sprays											•				
Kling, Chevalerias, Maman	1956	The Injection of Flashing Liquids by Impinging Jets			•											•	
Kling, Leboeuf	1956	Microphotographic Method											•				
Klumb	1954	New Methods for Production and Definition of Aerosols				•	•	•		•			•				
Kohler	1958	Thermodynamic Formulae for Surface Tension														•	
Kolmogorov	1949	Breakup of Droplets in Turbulent Streams	•	•													
Kolodner	1956	Instability of Liquid Surfaces II	•														
Kolodner	1954	Formation and Behavior of Aerosols	•														
Kolodner	1954	Jets Produced by Conical Nozzles		•													
Komabayasi, Gonda, Isono	1964	Time of Breaking and Size Distribution of Water Drops	•														
Korotkikh	1960	Utilization of Aerosol Apparatus														•	
Korotkikh	1957	Aerosol Generators														•	
Kottler	1951	Distribution of Particle Sizes												•			
Kottler	1950	Distribution of Particle Sizes												•			
Kraemer, Hans	1953	Homopolar Electrification of Aerosols						•									
Kramm	1953	Influence of Surf. Tens. on Drop Size				•										•	
Kruse, Hess, Ludvik	1949	Performance of Spray Nozzles for Insecticides		•		•											
Kuehn	1925	Atomization of Liquid Fuels		•									•				
Kuharjev	1939	Fuel Atomization for Diesel Engines				•											
Kuhn	1953	Breaking Up of Liquid Cylinders	•														
Kuhn, et al.	1959	Velocity of Breaking up of Liquid Cylinders	•														
Kulagin	1959	Angle from Centrifugal Nozzle		•													
Kurabayasi	1961	Atomization by Rotating Nozzle					•										
Kurabayasi	1960	Atomization of Liquid by Rotating Nozzle					•										
Kurabayasi	1960	Thickness of Jets from Nozzle		•			•										
Kutateladze, Strikovich	1958	Hydraulics of Gas-Liquid Systems (Book)		•		•											
Kuznetsov, Talaf	1958	Breaking Up of Fluid Jet		•													
Lacey et al.	1959	Particle Size of Aerosols								•							
Laguilharpe	1948	Atomizer-Dryer (French Patent)													•		
Lambrecht, Alvermann	1957	Atomization in Jet Engines		•			•									•	
Lane	1951	Shatter of Drops in Streams of Air	•	•											•		
Lane, Green	1956	Mechanics of Drops and Bubbles	•	•			•										
Lang	1962	Ultrasonic Atomization							•								
Lang, Young, Wilson	1962	Ultrasonic Oil Burner							•							•	
Lange, Davis	1959	Characteristics of Converging Nozzles			•												
Langer, Lieberman	1960	Atomization of Polystyrene Latsy														•	
Langlais	1950	Supersonic Aerosol Generator							•								
Larocombe	1947	Pressure Spray Nozzles		•													
Larsen, Joyce	1962	Atomization														•	
Lester, Doumas	1953	Theoretical and Mathematical Analysis of Nozzles														•	
Lastovtsev	1957	Analysis of Rotating Atomizers					•										

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Lastovtsev	1957	Capacity of Rotary Atomizers					•										
Lastovtsev	1950	Dispersion of Atomized Liquids		•			•							•			
Latham	1968	The Mass Loss of Water Drops Falling in Electric															
		Fields						•									
Lauterbach et al.	1955	Improved Aerosol Generator														•	
Lawrence	1948	Gas Turbine Accessory Systems		•													
Lebedev	1960	Spraying at Low Pressure and Low Output		•													
Lee	1935	Comparison of Fuel Sprays		•	•												
Lee	1932	Effect of Nozzle Design		•									•				
Lee	1932	Distribution of Fuel in Fuel Sprays		•													
Lee	1932	Fuel Spray Formation		•													
Lee, Spencer	1933	Photomicrographic Studies of Fuel Sprays		•									•	•			
Lee, Spencer	1932	Preliminary Photomicrographs of Fuel Sprays		•													
Leighton	1958	Instrumentation for Aerosols															•
Lewis, D. J.	1950	Instability of Liquid Surfaces		•													
Lewis, H. C. et al.	1948	Atomization in High Velocity Air Streams				•				•							
Lewis, J. D.	1963	Atomization and Injection Processes														•	
Limper	1947	Atomization in High Velocity Air Streams				•											
Littaye	1944	Influence of Air Velocity on Drop Diameter				•											
Littaye	1943	Atomization of a Liquid Jet				•											
Littaye	1943	Theory of Atomization of liquid Jets				•											
Littaye	1942	Study of Liquid Jets	•														
Loeb	1958	Static Electrification (Book)						•									
Lohnstein	1906	Theory of Drop Formation	•														
Longwell	1943	Fuel Oil Atomization		•													
Longwell, Weiss	1953	Mixing and Distr. of Liquids in High Velocity															
		Air Streams														•	
Lovikov	1955	Influence of Concentration on Drop Size					•								•		
Lubbock, Bowen	1948	Effect of Cone Angle, Pressure, Flow on Drop Size															
		of Pressure Jet Atomizer		•													
Luther	1962	Electrostatic Atomization						•									
Lyshevskii	1963	Axial Pressure in a Fluid Jet		•													
Lyshevskii	1963	Design of Jets		•											•		
Lyshevskii	1963	Velocity Distribution in Liquid Jets		•													
Lyshevskii	1961	Motion of Stream of Atomized Liquid		•													
Lyshevskii	1960	Breakdown of Viscous Jet		•													
Lyshevskii	1960	Development of a Jet		•													
Lyshevskii	1960	Motion of an Atomized Jet		•													
Lyshevskii	1958	Stability and Breakdown of Hollow Jet		•													
Lyshevskii	1958	Disruption of Hollow Jet of Liquid		•													
Lyshevskii	1957	Scattering of Liquid Streams		•													
Lyshevskii	1957	Widening of a Jet of Sprayed Liquid		•													
Lyshevskii	1957	Determination of Boundary Velocities		•													
Lyshevskii	1957	Influence of Turbulence on Disintegration		•													
Lyshevskii	1956	Coefficient of Free Turbulence		•													
Lyshevskii	1956	Numerical Determination of Fuel Jet Length		•													
Lyshevskii	1956	Determination of Jet Length		•													
Macky	1931	Deformation and Breaking of Water Drops in Electric															
		Fields						•									
Magarvey	[illegible]	Stain Method of Drop-Size Determination											•				
Magarvey, Outhouse	1962	Breakup of a Charged Liquid Jet						•									
Magarvey, Taylor	1956	Apparatus for Production of Water Drops							•							•	

AUTHOR	YEAR	TITLE OR SUBJECT	Atomization Techniques: Basic Principles	Hydraulic: Spray	Hydraulic: Impingement	Pneumatic	Rotational	Electrostatic	External Vibration	Flashing or Thermal	Explosive	Miscellaneous	Drop Size: Measurement Techniques	Drop Size: Distribution Data	Spray Drying	Other Application Areas	Liquid Properties and Property Measurement
Magarvey, Taylor	1956	Free Fall Breakup of Large Drops	•	•													
Magarvey, Taylor	1966	Shattering of Large Drops	•	•													
Mahrous	1952	Multi-Flash Camera in Study of Liquid Jets	•										•				
Manea, Stratulat, Munteanu	1962	Spraying of Liquid Fuels at Variable Pressure															
		and Temperature		•												•	
Mani, Nigam, Rao	1959	Atomization by Pressure Nozzles IV		•													
Mani, Rao	1958	Atomization by Pressure Nozzles III		•													
Mani, Rao	1957	Atomization by Pressure Nozzles I		•													
Manson, Banerjea, Eddi	1955	Microphotographic Study of Atom. of Liquid Fuels											•				
Marshall	1955	Heat and Mass Transfer in Spray Drying													•		
Marshall	1954	Atomization and Spray Drying	•	•	•	•	•						•	•	•		
Marshall, Seltzer	1950	Principles of Spray Drying		•	•	•	•						•	•	•		
Mascolo	1959	Effect of Entrained Gases on Atomization		•	•											•	
Mason	1964	Collision, Coalescence, Disruption of Drops			•											•	
Mason, Jayaratne, Woods	1963	Vibrating Device to Produce Uniform Water Drops							•								
Masugi	1956	Deformation and Atomization of Drops in Air Stream				•											
Matthews, Mason	1954	Electrification of Water Drops in an Electric Field						•									
Maxwell	1948	Study of Air Atomization				•											
May	1965	Graticule for Particle Counting and Sizing											•				
May	1960	Small Two-Fluid Atomizer				•											
May	1960	Uniform Drops from Vibrating Reed System							•								
May	1949	Spinning Top Homogeneous Spray Apparatus					•										
May	1945	The Cascade Impactor											•				
Maybank, et al.	1956	Magnetically Stabilized Disk for Homogeneous															
		Aerosol Production					•										
Mayer	1961	Liquid Atomiz. in High Velocity Gas Streams	•			•											
McCormack, et al.	1965	Analysis of Cylindrical Liq. Jets Subject to Vibra-															
		tion	•						•								
McCubbin	1953	Particle Size in Fog Produced by Ultrasonic															
		Radiation							•								
McEntee	1952	Atomization in Spray Drying													•		
McIrvine	1957	Atomiz. Viscous Liq. with Swirl Nozzles		•													
Mehlig	1934	Physics of Fuel Sprays in Diesel Engines		•										•			
Mehlig	1934	Method of Measuring Average Size of Diesel Fuel															
		Sprays											•				
Merrington, Richardson	1947	Break up of Liquid Jets	•	•		•							•				
Middleman, Gavis	1965	Transverse Wave Motion on Thin Jet of Fluid	•						•								
Middleman, Gavis	1961	Expansion of Capillary Jets of Viscoelastic Liquids		•													
Middleman, Gavis	1961	Expansion of Capillary Jets of Newtonian Liquids	•	•													
Miesse	1958	Effect of Altitude on Atomization Phenomena		•													
Miesse	1956	Recent Advances in Spray Technology	•	•													
Miesse	1956	Combustion of Atomized Liquid Propellants														•	
Miesse	1955	Correlation of Data on Disintegration of Liquid Jets	•	•													
Miesse	1955	Effect on Pressure Oscillations on Disintegration and															
		Dispersion of Liquid Jet							•								
Miesse	1955	Effect of Evaporation Rate on Ballistics of Droplets														•	
Miesse	1955	From Liquid Stream to Vapor Trail	•	•												•	
Miller	1960	Distribution of Spray from Impinging Liq. Jets			•												
Mina	1954	Ultra-Low Pressure Aerosols				•											
Misek	1963	Breakup of Drops by Rotating Disk					•										
Mock, Ganger	1950	Practical Conclusions on Gas Turbine Spray Nozzles		•												•	
Monk	1952	Viscous Energy Dissipated During Atomiz. of Liquid	•	•													
Morrell	1963	Liq. Jet Breakup by Transverse Shock Wave							•								
Morrell	1963	Rate of Liquid Jet Breakup				•			•								
Morrell	1961	Critical Conditions for Drop & Jet Shattering		•		•											

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			Atomization Techniques										Drop Size				
Morrell, Povinelli	1964	Breakup of Liquid Jets by Shock Waves and Appl. to Combustion							•							•	
Morris	1952	Atomizer for Use in Chromatographic Analysis														•	
Mugele	1960	Maximum Stable Droplets in Dispersoids												•			
Mugele, Evans	1951	Drop Size Distribution in Sprays												•			
Murashev	1948	Fuel Injection System with Rotating Chamber					•									•	
Narasimhan, Narayanaswamy	1963	Exp. Studies on Intermittent Airblast Sprays				•											
Nayyar, Murty	1960	Stability of Dielectric Jet in Electric Field						•									
Needham	1946	Correlation of Size Data on Pressure Jet Atomizers		•													
Nelson	1959	Drop Size Distr. from Centrifugal Spray Nozzles					•						•	•			
Nelson, Stevens	1961	Drop Size Distr. from Centrifugal Spray Nozzles					•						•	•			
Neubauer, Vonnegut	1953	Monodisperse Liquid Particles by Electrical Atomization						•									
Niepenberg	1959	Principles of Pressure Atomization	•	•		•	•						•	•			
Norgren	1962	Colloidal Particle Generator for Electrostatic Engines						•									
Northup	1951	Flow Stability in Small Orifices		•													
No[illegible]	1948	Laws of Atomization of Liquids by Centrifugal Nozzles		•													
Nukiyama, Tanasawa	1938	Atomization in an Air Stream				•											
O'Brien	1961	Why Raindrops Breakup - Vortex Instability	•														
Oderfeld	1954	Droplet Distribution in Sprayed Fuel											•	•			
Oesterle	1957	Influence of Electrostatic Fields on Varnish Atomization						•									
Ohnesorge	1936	Drop Formation in Nozzles and Breakup of Liquid Jets		•													
O'Konski, Thacher	1953	Theory of Distortion of Aerosol Droplets by Electric Field						•									
Olson	1959	Atomization of Liquid Fuels														•	
Osama	1956	Atomization of Liquid by High Voltage						•									
Oyama, Eguchi, Endou	1953	Trajectory of Water Droplets from Centrifugal Disk					•										
Oyama, Endou	1953	Theory of Centrifugal Disk Atomization					•										
Palmer, F. and Kinsbury	1952	Particle Size in Nebulized Aerosols				•								•			
Palmer, R.S.	1962	Water Jet Breakup from Stainless Steel Tubes		•													
Panasenkov	1951	Effect of Liquid Jet Turbulence on Atomization		•													
Panevin	1960	Atomization of Liquids in Colliding Jets	•		•												
Panevin	1960	Distribution of Liquids in Colliding Jets			•												
Park, Crosby	1968	Device for Producing Controlled Collision Between Drops	•													•	
Partington	1951	Properties of Liquids (Book)															•
Pattison, Aldridge	1957	Water Atomization by Spinning Disks					•						•	•			
Paul, Sleicher	1965	Effect of Pipe Diameter on Maximum Stable Drop Size in Turbulent Flow	•														
Payne	1958	Numerical Method for Calc. Jet Perturbation at Low Reynolds No.	•														
Perron, Swanton, Shanley	1963	Ultrasonic Burner							•								
Peskin, Raco	1964	Drop Size from Liquid Jet in Electric Field						•									
Peskin, Raco	1963	Ultrasonic Atomization of Liquids							•								

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Peskin, Raco	1963	Ultrasonic and Electrostatic Atomization						●	●								
Peskin, Lawler	1962	Analytical Study of D. plet Formation	●					●	●								
Pfaff-Grossmann	1955	Effect of Surface Tension on Drop Size Distribution		●									●	●			●
Pfa.:-Crossman	1954	Ef ect of Nozzle Size and Liquid Properties on															
		Size Distribution		●									●	●			●
Pfeiffer,	1964	Rebound of Drops from Solid Surface	●													●	
Piazza, Fittipaldi	1951/	Centrifugation of Films Adhering to a Divergent					●										
	1953	Rotor															
Pickroth, Spitzenberg	1954	Ultrasonic Nebulization							●								
Pierce, E. T.	1959	Effects of High Electric Fields on Dielectric Liquids						●									
Pierce, N. C.	1947	Efficiency of Hydraulic Nozzles for Atomization		●									●				
Pigford	1950	Auto. Determ. of Size Distr. of Liquid Sprays											●				
Pigford, Pyle	1951	Performance Characteristics of Spray-Type Absorbers		●													
Pilcher	1953	Characteristics of Sprays and Droplets											●	●			
Pilcher, Miesse	1957	Mechanism of Atomization	●														
Pilcher, Miesse	1957	Methods of Atomization	●	●	●	●	●		●			●					
Pilcher, Miesse	1957	Design of Atomizers		●	●	●											
Pilcher, Miesse, Putnam	1957	Spray Analysis											●	●			
Pilcher, Thomas	1958	Drop Size Distr. of Fuel Sprays											●	●			
Pischinger, Pischinger	1955	New Research on Fuel Jets		●												●	
Plateau	1873	Exp. and Theor. Studies of Liquids	●														
Plateau	1869/	Exp. and Theor. Studies of Liquids	●														
	1870																
Plateau	1849/	Exp. and Theor. Studies of Liquids	●														
	1868																
Plateau	1850	On the Stability of a Liquid Cylinder	●														
Plit	1962	Dispersion of a Liquid Jet by Gas				●											
Plockinger	1956	Characteristic Numbers of Atomization	●	●		●											
Pobiarzhin	1959	Influence of Internal Vorticity on Fuel Atomization		●									●				
Pohl	1961	Formation of Liquid Jets in Non-Uniform Electric															
		Fields						●									
Polyakov	1960	Exp. Invest. of Axially Symmetric Turbulent Jets														●	
Ponstein	1959	Instability of Rotating Cylindrical Jets	●														
Popov	1964	Quality of Spray from Ultrasonic Dispersion							●								
Popov	1956	Model Exp. on Atomization of Liquids	●														
Popov	1953	Invest. of Variable Spray Cone Injection Nozzle		●													
Popov, Goncharenko	1965	Ultrasonic Atomizers for Liquids and Melts							●								
Potts	1958	Concentrated Spray Equipment, Mixtures, and Methods												●		●	
Potts	1946	Particle Size of Insecticides in Application															
		and Deposition												●		●	
Pouston, Winter	1957	Air Flow and Fuel Droplet Distr. in Combustion															
		Systems		●												●	
Pozzi	1962	Jets in a Medium of Different Properties	●														
Priem	1957	Breakup of Water Drops and Sprays with a Shock Wave							●								
Probert	1946	Influence of Spray Size and Distr. on Combustion												●		●	
Probst	1964	Spherical Metal Powders			●											●	
Probst	1962	Production and Use of Spherical Metal Powders			●											●	
Probst	1959	Atom. Nozzle and Assembly for Mfg. Metal Powders			●											●	
Prokonenko	1957	Geometric Aspects of Vortex Atomizing Nozzles		●												●	
Putimtsev, Gratsiasov	1960	Metal Powders by Atomization (U.S.S.R. Patent)				●										●	
Putnam	1961	Integrable Form of Droplet Drag Coeff.														●	
Putnam, et al.	1957	Injection and Combustion of Liquid Fuels	●	●	●	●	●		●			●	●	●			
ivenkov	1957	Theor and Exp. Invest. of Liquid Fuel Atom.		●												●	

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Rabin, Lawhead	19[illegible]	Shattering of Propellant Drops														●	
Rabin, et al.	1960	Shattering of Propellant Drops														●	
Radcliffe	1955	Performance of Swirl Atomizer		●													
Radcliffe	1954	Performance of Swirl Atomizer		●													
Radcliffe, Clare	1953	Performance of Air Blast Atomizers				●											
Railleres, Avy	1954	Fine Atomization of Liquids										●?					
Rammler	1956	Laws of Particle Distribution												●			
Rammler	1955	Special Log-Table for RRS Distribution												●			
Randall, Marshall, Tschernitz	1964	Atomization by Electrical Energy						●									
Rans	1959	Dynamics of Liquid Films	●														
Rans	1958	Experiments on Orifice Sprays		●									●	●			
Rans	1958	Mechanical Formation of Aerosols		●													
Rans	1956	On Sprays and Spraying	●	●	●	●	●						●	●			
Rans, Hofelt	1957	Determining Drop Size Distribution											●	●			
Rao, M. N.	1960	Atomization in Pressure Nozzles		●													
Rao, S.P. and R. Kaparthi	19[illegible]	Drop Formation at Nozzle Tips	●														
Rapaport, Weinstock	1955	Generator for Aerosols														●	
Rasbash	1955	Properties of Sprays by Impinging Jets			●												
Rasbash	1953	Water Spray by Hypodermic Needles		●													
Rasbash, Stark	1957	Distribution of Spray		●													
Rayleigh	1920	Scientific Papers	●													●	
Rayleigh	1892	Instability of Cylinder of Viscous Liquid	●														
Rayleigh	1890	Tension of Water Surfaces															●
Rayleigh	1890	Tension of Recently Formed Liquid Surfaces															●
Rayleigh	1890	Theory of Surface Forces															●
Rayleigh	1882	Instability of Liquid Charged with Electricity						●									
Rayleigh	1882	Further Observations on Liquid Jets	●														
Rayleigh	1879	Instability of Jets	●														
Rayleigh	1879	Capillary Phenomena of Jets	●														
Rayleigh		The Theory of Sound	●														
Rayner, Haliburton	1955	Rotary Device for Uniform Drops					●										
Rayner, Hurtig	1954	Apparatus for Drops of Uniform Size										●?				●	
Reed	1953	Effect of Airplane Wake on Aerial Sprays														●	
Reményi	1959	Theoretical Investigation of Atomizers														●	
Retel	1938	Contributions to Study of Diesel Injection		●									●			●	
Reure, Paris	1958	Smoke, Fog, Aerosol Generator (U.S. Patent)														●	
Reynolds	1965	Stability of Electrostatically Supported Fluid Column						●									
Richardson, E. G.	1960	Aerodynamic Capture of Particles (Book)														●	
Richardson, E. G.	1954	Disruption of Liquid Jet	●														
Richardson, E. G.	1953	Liquid Sprays	●	●									●				
Richardson, E. G.	1952	Dispersing High-Boiling Liquids (U.S. Patent)														●	
Richardson, J. F. and E. R. Wooding	1956	Photographic Method of Analysing Aerosols											●				
Riddell	1954	Jettisoning of Liquids from Airplane	●													●	
Riley	1962	Asymtotic Expansions in Radial Jets														●	
Rius et al.	1957	Spraying by Centrifugal Discs					●								●		
Roller	1937	Law of Size Distribution												●			
Romp	1937	Oil Burning		●	●	●	●						●			●	
Root	1957	Aerosol Spray Patterns											●?				
Rose	1962	Strongly Swirling Jet		●													
Rosenthal	1949	Device for Dispensing Liquid Fuel (U.S. Patent)							●								
Rosenthal	1948	Apparatus for Dispensing Liquid Fuel (U.S. Patent)							●								
Rosin, Rammler	1933	Laws of Fineness of Powdered Coal												●			
Rosenberg, Eknadiosyants	1960	Kinetics of Ultrasonic Fog Formation							●								
Rumscheidt, Mason	1962	Breakup of Stationary Liquid Threads	●														

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Rumscheidt, Mason	1961	Particle Motions in Sheared Suspensions. III	•														
Rupe	1956	Spray from Pair of Impinging Jets			•												
Rupe	1[illegible]3	Liquid-Phase Mixing of Jets			•												
Rupe	1953	Semi-Automatic Size Differentiating Counter											•				
Rupe	1950	Injector Spray Sampling											•				
Rupe	1949	Characteristics of Constant Flow Nozzles		•									•				
Ryan	1948	Impingment of Unconfined Jets			•												
Ryley	1959	Efficiency of Spinning-disc Atomiser					•										
Ryley	1959	Transition of Atomisation Type					•										
Ryley	1959	Analysis of Spray from Spinning Disc Atomiser					•										
Ryley	1958	Electrically Driven Disc Atomiser					•										
Ryley, Wood	1963	Vibrating Capillary Atomiser							•								
Saffman, Turner	1956	Collision of Drops in Turbulent Clouds														•	
Salcas-Serra, Planaguma	1957	Mechanical Atomizer (German Patent)										•?					
Sandomirskii	1958	Condition of Surface of Jet Orifices		•													
Sass	[illegible]30	Heavy-Oil Engine Problems		•													
Sass	1949	Kompressorlose Dieselmaschinen (Book)		•									•				
Sauter	1928	Atomization in Carburetors				•										•	
Sauter	1926	Determining Efficiency of Atomization												•			
Sauter	1926	Determination of Drop Size											•	•			
Savart	1834	Impact of Two Liquid Jets			•												
Savart	1833	Structure of Liquid Jets		•													
Savic	1953	Heat Transfer in Spray Droplets	•													•	
Savic	1953	Distortion of Liquid Drops	•													•	
Schone	1960	Atomization Processes in Spray Painting														•	
Scheubel	1927	On Atomization in Carburetors				•							•				
Schlick	1957	Electrically Charged Atomizer (German Patent)						•									
Schmarbeck	1951	Compressed-Air Atomizing of Pesticides (German Patent)				•											
Schmidt	1949	Atomization of Liquids Injected into Air Stream											•				
Schmidt	1949	Injection into a Low-Pressure Chamber		•													
Schmidt	1948	Drop Size by Diffraction Ring Method											•				
Schmidt	1946	Application of Photoelectric Photometer											•				
Schneider, Hendricks	1964	Uniform-Sized Liquid Droplets		•				•				•					
Schneider, Lindblad, Hendricks	1965	Apparatus to Study Collision and Coalescence of Liquid Aerosols														•	
Schreiner	1957	Design of Spray Nozzles		•	•	•											
Schultze	1961	Behavior of Liquids during Electrostatic Atomization						•									
Schwarz, Rasmer	1966	Equation for Size Distribution													•		
Schweitzer	1937	Mechanism of Disintegration		•													
Seebaugh, Lee	1963	Optical Method for Observing Breakup											•				
Seidl	1952	Oil Fountains by Ultrasonics							•								
Semerchan *et al.*	1960	Supersonic Liquid Jets														•	
Semerchan *et al.*	1960	Supersonic Liquid Jets at 30,000 psi														•	
Semerchan *et al.*	1958	Distribution of Momentum in Fluid Jet														•	
Shafer, Bovey	1954	Application of Dimensional Analysis		•										•			
Shapiro, Erickson	1966	Changing Size Spectrum of Particle Clouds														•	
Shaw	1950	Efficient Sprayer														•	
Shcherbakov, Boletin	1964	Relation of Surf. Tens. to Radius of Drop															•
Shimoosaka	1940	Forms of Jets from Nozzles	•														
Siderov	1957	Laminar Flow of Drop-forming Liquids														•	•
Siemes, Kaufmann	1957	Drop Formation in Nozzles at High Flow Rates		•									•	•			

AUTHOR	YEAR	TITLE OR SUBJECT	Atomization Techniques										Drop Size				
				Hydraulic													
			Basic Principles	Spray	Impingement	Pneumatic	Rotational	Electrostatic	External Vibration	Flashing or Thermal	Explosive	Miscellaneous	Measurement Techniques	Distribution Data	Spray Drying	Other Application Areas	Liquid Properties and Property Measurement
Siestrunk	1942	Breaking-up Process of Liquid Jets				•											
Sitkei	1960	Mixture Formation in Diesel Engines	•	•												•	
Sitkei	1959	Theory of Jet Atomization	•	•													
Skalamera	1953	Aut atic Analysis of Size Distribution Data											•				
Sleicher, et al.	1960	Fluid Dyn mics (Review)														•	
Sliepcevitch, et al.	1950	Vibrating-Type Atomizing Nozzle							•								
Smith, D. A.	1949	Spray Drying Equipment													•		
Smith, S. W. J. and H. Moss	1917	Experiments with Mercury Jets		•													
Söhngen, Grigull	1951	Fuel-Injection Nozzles of Swirl Type		•													
Sokolov, Reshanov	1960	Subdivision of Droplets in Spraying														•	
Söllner	1936	Formation of Fogs by Ultrasonic Waves							•								
Somin, Pismennyi	1961	Atomizer for Low Concentrations														•	
Somogyi, Feller	960	Drops of Spray by Impinging Streams			•												
Sorokin	1957	Fountain of Drops	•														
Southern Research Inst.	1959	Particle Size of Aerosols from Hot-Gas Atomization								•							
Squire	1953	Instability of Moving Liquid Film	•														
Squire	1952	Instability of Moving Liquid Film	•														
Srinivas, Rao, Rao	1956	Disk Atomization					•										
Stamm	1960	Aerosol Production with Ultrasonics							•								
Stange	1953	Size Distribution Laws												•			
Sterling	1952	Injector Spray and Hydraulic Factors														•	
Stehling, Porter	1954	Liquid Jet Atomization by Sonic Nitrogen Stream				•											
Stepanov	1947	Apparatus for Atomizing Liquids (U.S.S.R. Patent)										•?					
Stoker	1946	Size of Droplets in a Gas											•				
Straubel	1954	Electrostatic Atomization of Liquids						•									
Straubel	1953	Electrostatic Atomization of Liquids						•									
Straus	1949	Mechanics of Drop Formation in Sprays (Thesis)		•													
Strashevsky	1937	Atomization of Liquid Fuel														•	
Stubbs, York	1951	Photographic Analysis of Sprays											•				
Szlachin	1947	Atomization at Low Injection Pressures		•													
Talakvadze	1961	Theory and Design of Centrifugal Nozzle		•													
Tamura, Takeda	1963	Copper Powder by Atomization				•											
Tanasawa, Hiroyasu	1962	Drop Size Analyzer											•				
Tanasawa, Kobayasi	1955	Swirl Atomizers		•													
Tanasawa et al.	1956	Uniform Drops with Rotating Nozzles					•										
Tanasawa et al.	1958	Impingment Nozzles for Diesel Engines			•												
Tanasawa et al.	1957	Atomization by Flat Impingment			•												
Tanasawa, Tesima	1958	Combustion of Liquid Fuel Spray														•	
Tanasawa, Toyoda	1954	Atomizing Characteristics of Injectors		•	•												
Tanasawa, Toyoda	1955	Atomization of Liquid Jet from Cylindrical Nozzle															
Tate	1965	Sprays and Spraying for Process Use. I, II	•	•	•	•	•								•	•	
Tate	1961	Immersion Sampling of Spray Droplets											•				
Tate	1950	Atomization by Pressure Nozzles (Thesis)		•													
Tate, Marshall	1953	Atomization by Centrifugal Pressure Nozzles		•													
Taylor, E. H. and D. B. Harmon	1954	Measuring Drop Sizes in Sprays											•				
Taylor, G.	1960	Formation of Thin Flat Sheets of Water	•														
Taylor, G.	1959	Dynamics of Thin Sheets. I. Water Bells	•														
Taylor, G.	1959	Dynamics of Thin Sheets. II. Waves on Fluid Sheets	•														
Taylor, G.	1959	Dynamics of Thin Sheets. III. Disintegration of															
		Sheets	•														
Taylor, G. I.	1960	Converging Nozzle of Swirl Atomizer		•													
Taylor, G.	1950	Instability of Liquid Surfaces when Accelerated. I.	•														

AUTHOR	YEAR	TITLE OR SUBJECT	Atomization Techniques: Basic Principles	Hydraulic: Spray	Hydraulic: Impingement	Pneumatic	Rotational	Electrostatic	External Vibration	Flashing or Thermal	Explosive	Miscellaneous	Drop Size: Measurement Techniques	Drop Size: Distribution Data	Spray Drying	Other Application Areas	Liquid Properties and Property Measurement
Taylor, G. I.	1948	Mechanics of Swirl Atomizers		•													
Thew	1932	Drop Sizes in Fuel Oil Spray											•	•			
Thiemann	1934	Influence of Air Viscosity and Density on Atomization		•													
Thomas	1952	Absorption and Scattering of Radiation by Drops											•			•	
Thring	1955	Combustion of Atomized Fuels. I.														•	
Tipler	1962	Measurement and Significance of Fuel Spray Momentum														•	
Tomotika, Aoi	1950	Steady Flow of Viscous Fluid Past a Sphere	•													•	
Tonks	1936	Instability of Droplets in Strong Electric Fields						•									
Townley	1953	Venturi Atomizer in Spray Dryer													•		
Troesch	1963	Free Fall of Drops in Air		•													
Troesch	1959	Breakup and Determination of Drop Size											•				
Troesch	1954	Atomization of Liquids		•	•	•	•?									•	
Troesch, Grassmann	1953	Law of Particle Size from Atomization												•			
Tsui	1965	Electrokinetic Pumping of Insulating Liquids						•									
Tsutsui	1931	Rupture of Liquid Drops			•												
Tsyurupa, Terekhova	1964	Classification of Disperse Systems														•	
Turbo	1962	Mechanism of Jet Disintegration	•														
Turner, Moulton	1953	Drop-Size Distribution from Spray Nozzles		•													
Tyler	1933	Instability of Liquid Jets	•										•				
Tyler, Richardson	1925	Curve of Liquid Jets		•													
Tyler, Watkin	1932	Exp. with Capillary Jets	•	•													
Uberoi, Chow	1963	Instability of Current-Carrying Fluid Jet						•									
Ueyama	1957	Size of Drops from Single Nozzles		•										•			
Ullrich	1960	Flow Phenomena in Swirl-Type Burners		•													
Ullrich	1959	Mechanism of Flow in Swirl Burners		•													
Ul'yanov	1954	Breaking Down of Liquid in Nozzles														•	
U S. Army Chem. Corps	1953	Physics of Aerosol Formulation (Bibliography)														•	
Uvarov	1955	Entrainment of Liquid by Gas or Steam														•	
Valdenassi	1954	Form of Jet from a Swirl Atomizer		•													
van Rossum	1959	Wave Formation, Atomization, Film Thickness				•						•					
Venkata	1960	Sprays in Spray Dryers													•		
Vereshchagin et al.	1956	Hydrodynamics of Jets		•									•				
Vereshchagin et al.	1959	Breakup of High Speed Jets		•													
Vereshchagin et al.	1957	Water Jets at 2000 Atmospheres		•													
Viilu	1962	Minimum N(Re) for Instability of Free Jet		•													
Vitman	1956	Density of Irrigation by Atomized Jet				•											
Vivdenko, Shabalin	1966	Mechanism of Jet Breakup		•													
Volynskii	1960	Atomization of Liquid in Supersonic Flow				•			•								
Volinskii	1949	Drop Disintegration in a Gas Stream	•														
Volinskii	1948	Disintegration of Drops in an Air Stream	•														
Vonnegut, Neubauer	1953	Supplement to Production of Monodisperse Particles						•									
Vonnegut, Neubauer	1952	Detection and Measurement of Aerosol							•								
Vonnegut, Neubauer	1952	Production of Monodisperse Particles						•									
Vörös	1935	Spray Drops in Agricultural Nozzles	•	•												•	
Vulis (editor)	1956	Conference on Applied Gas Dynamics		•												•	

AUTHOR	YEAR	TITLE OR SUBJECT	Atomization Techniques										Drop Size				
				Hy-draulic													
			Basic Principles	Spray	Impingement	Pneumatic	Rotational	Electrostatic	External Vibration	Flashing or Thermal	Explosive	Miscellaneous	Measurement Techniques	Distribution Data	Spray Drying	Other Application Areas	Liquid Properties and Property Measurement
Wade	1952	Recurrent Figure of a Jet	•														
Wade	1930	Sinuous Ripple of a Cylindrical Flow	•														
Walker	1956	Distribution of Insoluble Particles in a Spray														•	
Walton, Prewett	1949	Uniform Drop Size by Spinning Disc Sprayers					•							•			
Walton, Prewett	1947	Spinning Top Sprayers for Homogeneous Sprays					•										
Watson	1947/	Fuel Systems for the Aero-Gas Turbine		•												•	
	1948																
Watson	1944	Design of Swirl Atomizers		•													
Weber	1931	Disintegration of Liquid Jets		•													
Weibull	1951	Statistical Distribution Functions												•			
Weinberg	1952	Heat Trans. to Low Pressure Sprays		•									•			•	
Weiss	1961	Atomization in High Velocity Air Streams (Thesis)				•											
Weiss, Worsham	1959	Atomization in High Velocity Air Streams				•											
Weiss, Worsham	1958	Atomization in High Velocity Air Streams				•											
Wenk	1956	Aerosols (German Patent)							•								
Wenk	1955	Aerosols (German Patent)							•								
Wetzel	1951	Venturi Atomization				•											
Wheeler, Trickett	1953	Size Distribution of Spray Particles											•				
White, Tallmadge	1965	Drag Out of Liquids on Flat Plates	•														
Widmer	1965	Formation of Drops in a Pulsating Liquid														•	
Wieber, Mickelsen	1960	Effect of Oscillations on Vaporization of Drops														•	
Wigg	1960	Drop Size Prediction for Twin Fluid Atomizers				•											
Wigg	1959	Effect of Scale on Spray				•											
Wilcox	1958	Breakup of Liquid Droplets		•													•
Wilcox, June	1961	Breakup of Drops in High Velocity Air				•			•								
Wilcox, et al.	1966	Effect of Polymeric Modifiers on Breakup				•			•								
Wilcox, Tate	1965	Atomization in High Intensity Sound Field							•								
Wilde	1959	Condensation in Nozzles														•	
Williams	1958	Spray Combustion and Atomization	•											•			
Williamson, Taylor	1958	Particle Counts by Spray Drop Method											•				
Willits, Connelly	1952	Atomizer for Flame Spectrophotometry														•	
Wilson	1936	Optical Size Measurement Methods for Small Drops											•				
Wooltjes	1925	Fineness of Atomization in Oil Engines		•		•											
Wolf, H. F.	1950	Liquified Gas Aerosols														•	
Wolf, W. R.	1961	Vibrating Reed Production of Small Droplets							•								
Wolfe, Anderson	1964	Kinetics, Mechanism, Drop Size of Breakup Drops				•											
Woolridge	1956	Determination of Spray Droplet Size											•				
Yaborskii	1958	Flow of a Single Jet														•	
Yager	1952	Atomizing Oil with Natural Gas														•	
Yeager, Coffin	1961	Air-Atomizing Oil Burners				•										•	
Yeomans	1955	Particle Size of Liquified-Gas Aerosols											•				
Yeomans	1949	Particle Size of Aerosols and Fine Sprays											•				
Yeomans	1948	Field-Model Aerosol Machines														•	
Yeomans, Rodenstein	1947	Exhaust Aerosol Generator for 1-1/2 H.P. Motors														•	
Yeomans, Rodgers	1953	Deposit of Spray Droplets														•	
York	1953	Methods of Experimental Study of Spray											•				
York, Stubbs	1952	Photographic Analysis of Sprays											•				
York, Stubbs	1951	Photographic Analysis of Sprays											•				
York, Stubbs, Tate	1953	Disintegration of Liquid Sheets		•									•				

AUTHOR	YEAR	TITLE OR SUBJECT	Atomization Techniques: Basic Principles	Hydraulic: Spray	Hydraulic: Impingement	Pneumatic	Rotational	Electrostatic	External Vibration	Flashing or Thermal	Explosive	Miscellaneous	Drop Size: Measurement Techniques	Drop Size: Distribution Data	Spray Drying	Other Application Areas	Liquid Properties and Property Measurement
Yurkstas, Meisenzehl	1964	Homogeneous Aerosols by Electrical Atomization						•									
Yutkin, Gol'tsova	1963	Electrohydraulic Atomizing (Soviet Patent)							•			•					
Zager	1963	Discrete Disperse Systems												•			
Zawidski et al.	1963	Vonnegut's Spraying Fountain						•									
Zeleny	1935	Surface Instability in Elec. Discharges from Drops						•									
Ziabicki, Takserman-Krozer	1963	Formation and Breakage of Liquid Threads. III.	•														
Ziabicki, Takserman-Krozer	1963	Formation and Breakage of Liquid Threads. II.	•														
Ziabicki, Takserman-Krozer	1963	Formation and Breakage of Liquid Threads. I.	•														
Zuev	1966	Attenuation of Radiation by Water Fogs											•			•	

B. Primary Survey

Open Literature and Government Report Literature References for Period of January 1950 through August 1965

1. Anonymous

"Safe, Low Cost Process for Handling Sulphur." European Chem. News, Dec. 11, 1964, p 36.

2. Anonymous

SOVIET RESEARCH AND DEVELOPMENTS IN INSECTICIDES AND METHODS OF APPLICATION.
10 Aug 60, 11p. JPRS: 3670.
Order from OTS $0.50 60-31640

Trans. of Zashchita Rastenii ot Vrediteley i Bolezney (USSR) 1960 [v. 5] no. 3, p. 13, 15-18, 34 and 61. Another translation of each item is available from LC or SLA mi$1.80, ph$1.80 as 60-17940, 60-17938, 60-17948 and 60-17943 respectively.

Contents:
A Sprayer with Revolving Atomizers, by A. V. Fomikov
Chemical Method of Combatting Wheat and Barley Smut, by I. M. Polyakov
New Organic Fungicides, by M. P. Umnov
In the All-Union Academy of Agricultural Sciences imeni Lenin (VASKhNIL) by O. A. Aleshina

T4-368

3. Anonymous

"Disintegration of a Water Droplet." Chem. Age (London) 63, 257 (Aug 19, 1950)

4. Anonymous

Investigations into Fuel Injection in Diesel Engines (in Engl.). Anon. Sulzer Techn. Rev. (Switzld.), No. 3 (1949), pp. 1–11, 20 fig.

Experiments investigating laws of injections by quantitative measurements by means of a rotating set of interceptor tubes of Plexiglass, and spray development by stroboscopic observation. Spray formation was observed directly with a stroboscope; photographs of spray development and dispersion are included, showing breakup into filaments and drops. Jet formation and disintegration shown with differences of flow velocity within the jet.

deJ I-334

5. Anonymous

Recent Developments in the Airless Injection of Fuel in Diesel Engines (in Engl.). Anon. Sulzer Techn. Rev. (Switzld.), No. 3 (1929).

Examination of degree of atomization at various distances from nozzle; splitting-up of drops.

deJ I-334

A-1. Abdyldaev, M.

2170. Abdyldaev, M., Investigation of a three-dimensional thin-layer jet flow (in Russian), *Izv. Akad. Nauk SSSR, Otd. Tekh. Nauk, Mekh. i Mash.* no. 6, 120–124, Nov./Dec. 1960.

The potential flow of a thin layer of inviscid fluid, adjacent to the surface of a solid and resulting from a jet directed toward the obstacle, forms starting point for some mathematics, the merits of which this reviewer feels unable to appreciate.

AMR 15-2170

A-2. Abramovich, G. N.

Teorija turbulentnih struj (Theory of turbulent jet). G. N. Abramovich (ZAGI, Moskva, USSR). Izd. fiz.-mat. literaturi, Moscow, 1960. 715 p., 351 fig.

This is an extensive monography; treats turbulence theories of Prandtl, Tollmien, Taylor, and Reichardt, with critical comments, and with their application to free turbulent jets. Discusses several cases of turbulent jets: in a medium flowing in various directions, in the presence of flame front, in collisions at various angles. Treats determination of velocity and temperature profiles, and calculation of mixing processes. Includes results of theoretical and experimental researches in USSR till 1960.

Available in English Translation, MIT Press, 1960

deJ II-4

A-3. Abramovich, G. N.

"Theory of the Centrifugal Nozzle," p. 18 f.f. in "Industrial Aero-dynamics," ZAGI, Moscow, 1944.

A-4. Adler, C. R.

"The Atomization of Water with Spinning Discs," Ph.D. Thesis, University of Wisconsin, 1950.

A-5. Adler, C. R., et al.

3774. Adler, C. R., Mark, A. M., Marshall, W. R., and Perent, R. J., A scanning device for determining size distribution of spray droplet images, *Chem. Engng. Prog.* 50, 1, 14–23, Jan. 1954.

A scanning instrument is described for counting and classifying spray drop images on photographic negatives. These negatives, mounted on a rotating drum, are projected by an optical system and focused at the plane of a mask containing a small aperture and located directly in front of a photomultiplier tube. As the droplet images rotate past this aperture they are simultaneously advanced a small distance at each revolution of the rotating drum. Thus the phototube receives through the aperture a series of light pulses whose durations correspond to the lengths of the chords of the circular image of the drops passing across the aperture. These light pulses of various time durations are converted into electrical pulses and fed into electronic sorter-counter circuits which classify the chords into fifteen size classes. A statistical treatment of this chord distribution is then made to give drop-size distribution. Tables of coefficients have been computed to permit rapid conversion of the chord distribution to drop-size distribution. The statistical theory for these coefficients is explained.

Tests on actual spray samples and on special test negatives demonstrated that the device will rapidly count and classify drops with acceptable accuracy. The scanning rate can be as high as 10,000 drops in 15 min at maximum drum speed, with greater accuracy than could be done by a human operator. Its main limitation is that it requires transparent images on photographic negatives; this in turn requires sampling of sprays on greased or soot-coated slides and photographing them. Apparatus is described in detail; data on actual sprays are given, and plotted in frequency curves.

AMR 10-3774

A-6. Adler, C. R., and W. R. Marshall

683 Performance of Spinning Disk Atomizers. Part I. C. R. Adler and W. R. Marshall, Jr. *Chemical Engineering Progress* (Engineering Section), v. 47, Oct. 1951, p. 515-522.

An investigation was made of the above. Studies were made of the effect of disk speed, feed rate, and air pumping by the disk on power requirements and spray weight distribution. An equation was recommended for estimating power for disk atomizers. A mathematical analysis of the velocity of liquid flow on spinning disks led to a nonlinear ordinary differential equation, which was solved for various conditions on IBM punched card machines.

BMI 1-683

A-7. Adler, C. R., and W. R. Marshall

1816 Performance of Spinning Disk Atomizers. Part II. (Concluded.) C. R. Adler and W. R. Marshall, Jr. *Chemical Engineering Progress* (Engineering Section), v. 47, Dec. 1951, p. 601-607; disc., p. 607-608.

Results of experiments are tabulated, charted, illustrated, and discussed. 57 ref.

BMI 1-1816

A-8. Aerojet-General Corp.

Author Unknown

Bimonthly Prog. Rpt. 0395-04(03)BP (May/June 1962)

Contract No. DA 18-108-405 CML 829

"Research Study on Dissemination of Solid and Liquid Agents," pp. 47-56 on "Aerodynamic Breakup."

July 12, 1962

A-9. Ailam, G, and I. Gallily

11345 STABILITY OF AN ELECTRICALLY CHARGED DROPLET. G.Ailam(Volinez) and I.Gallily. Phys. of Fluids (USA), Vol. 5, No. 5, 575-82 (May, 1962).

The stability of an electrically charged droplet with respect to mechanical deformations is studied under the assumptions that the liquid is perfectly conducting, the medium devoid of external fields of force, and the sum of the electrical and mechanical energies in the system conserved. Unlike Rayleigh's case, which dealt with small perturbations of spherical drops, the deformations considered in the present case are allowed to be large in size but confined to shape to ellipsoids of revolution. The energy of the deformed droplet is expressed as a function of a geometrical parameter and the ratio α between the electrical and surface energies of the corresponding spherical shape. Likewise, the dependence of the extremal points on α is investigated. Conforming with Rayleigh, the spherical droplet is shown to be unstable for $\alpha > 4$ and stable for $\alpha < 4$. However, for a certain range of α in the latter case, it is found to be only in a metastable state. In addition, both one prolate and one oblate ellipsoid of minimal energy are shown to exist for every $\alpha > 4$.

PA 65-11345

A-10. Akimenko, A. D.

3060. Akimenko, A. D., Characteristics of the outflow of water atomizers (in Russian), *Vodosnabzh. i San. Tekhn.* no. 11, 11-13, 1959; *Ref. Zh. Mekh.* no. 8, 1960, Rev. 10087.

Author states that in calculating the volume of outflow Q from a water sprayer the correct formula $Q = Bd^2\mu\sqrt{P}$ should be used, and not the formula $Q = Ad\sqrt{P}$, which holds only for similar sprayers with identical orifice diameter d. Here P is the pressure before the spray (more exactly, the fall of pressure over the sprayer), μ is the coefficient of outflow, and A, B are constant coefficients. For certain types of sprayer the values of μ are given for different Reynolds numbers and ratios of the diameter of the orifice of the spray to its length.

AMR 16-3060

A-11. Alterman, F.

6535. Alterman, Z., Capillary instability of a liquid jet, *Physics of Fluids* 4, 8, 955-962, Aug. 1961.

Stability of a cylindrical liquid jet streaming within a surrounding liquid is discussed when the jet is in pure axial motion with additional rotation and with a superposed magnetic field. Author concludes that: (1) a static jet, which is unstable for axisymmetric perturbations of wavelengths exceeding its circumference, is stabilized by a sufficiently strong magnetic field; (2) rotation causes stability or instability depending on the relative angular velocities of jet and surroundings; (3) a jet in axial motion is unstable even in a magnetic field; (4) for a given velocity, the jet is stable only for perturbations with wave numbers exceeding a certain value.

AMR 15-6535

A-12. Amer. Soc. for Testing Matl.

"Symposium on Particle Size Measurement," presented at the 61st Annual Meeting, ASTM, Boston, June 26-27, 1958. ASTM Spec. Tech. Pub. No. 234.

A-13. Amsden, R. C.

• A Laboratory Apparatus for the Continuous Production of Uniform Droplets. The development, liquid feed, droplet diameter control, velocity of droplets, target movement, disadvantages and uses are discussed. *R. C. Amsden. AVC, Agricultural & Veterinary Chemicals*, v. 1, no. 3, Sept.-Oct. 1960, p. 139-140.

BMI 10-180a

A-14. Anson, D.

Influence of the Quality of Atomization on the Stability of Combustion of Liquid Fuel Sprays. D. Anson. (Dep. of Sci. and Ind. Res., Wellington, New Zealand). Fuel, Vol. 32, No. 1 (1953), pp. 39-51, 8 fig., 7 ref.

Combustion experiments with kerosine sprayed from an air-blast atomizer. By using a series of different injection pressures a family of curves were obtained representing the weak limits of stable combustion for each case. It was possible to relate the stability limit at a given air stream velocity to the spray mean particle size. Fine atomization was found to extend the range of stable combustion, but an optimum article size may exist for any given scale of turbulence in the combustion chamber. The apparatus comprised a centrifugal blower which could supply up to eight pounds of air per minute, which could be regulated and measured; the kerosine was fed under pressure up to about 60 psi, at an adjustable temperature and at an adjustable rate; atomization was by air blast, whereby the relative proportion of blast air and fuel could be regulated; the flame tube was fitted with mica windows, ignition was by platinum wire. The results of the tests are represented in curves.

deJ I-11

A-15. Antonevich, J. N.

4342. ULTRASONIC ATOMIZATION OF LIQUIDS.
J.N. Antonevich.
I.R.E. Trans Ultrasonics Engng. No. PGUE-7, 6-15 (Feb., 1959).

Observations of liquid films excited ultrasonically are described and discussed. These films atomized under ultrasonic excitation, and the rupture of capillary waves in the film is suggested as the prime cause of atomization. The atomization of a paint film by 20 kc/s vibrations was studied qualitatively. High-speed motion pictures show sprays emanating from vibrating gas bubbles in the paint film. The particles produced were from 5 to 500 μ in diameter. Under the best atomizing conditions at 20 kc/s the particle diameters were from 20 to 70 μ.

PA 62-4342

A-16. Arni, V. R. S.

Ph.D. Thesis, University of Washington, 1959.

THE PRODUCTION, MOVEMENT AND EVAPORATION OF SPRAYS IN SPRAY DRYERS.

(L. C. Card No. Mic 59-5454)

Venkata Rao Sahib Arni, Ph.D.
University of Washington, 1959

Preliminary investigations dealing with the possibility of using an existing four-foot diameter pilot-scale spray dryer for evaporation studies indicated unfavorable velocity distributions within the drying chamber. A tower-type spray dryer, 24 feet high and 8 inches in diameter, was constructed to offset this disadvantage. The first stage of this study was related to the effect of the air-entry design on the velocity profiles in the two dryers. A subsequent study was made to determine the influence of physical and chemical properties of liquids on the disintegration of viscous jets. As a result of this work, potassium carbonate solutions and nitrobenzene were selected as suitable spraying materials for an investigation of evaporation rates. The subject matter of the thesis is divided into three separate but related parts.

Part I. The Effect of Air-Entry Design on the Distribution of Velocities in Spray Dryers -- A single-coil hot-wire anemometer was constructed and used along with a suitable Kelvin-Bridge to determine velocity profiles in a chamber-type dryer designed by Buckham and Moulton and in the tower-type spray dryer. The former had a straight air-entry system with an eight member web-type distributor for dispersing the air. The tower dryer was also installed with a straight air-entry but was provided with a set of two 60-mesh screen distributors. The data for the chamber dryer showed highly peaked velocity distributions, the maximum velocity being attained in the neighborhood of the central vertical axis. The magnitude of the peak velocity, (1) was several fold higher than average dryer velocity, (2) varied with vertical position, (3) diminished with decreasing inlet velocity, (4) varied with angular position. The shape of the profile, (1) was conserved for varying flowrates, (2) remained unaltered for a major portion of the dryer height, and (3) was little affected by the design of the air-exit system. The flow pattern was ascribed to the jet-type action of the inlet duct, the web-distributor being almost totally ineffective. The data also indicated stagnant pockets of air in the drying chamber. The tower-dryer showed relatively uniform flow patterns for a considerable portion of its length. In the vicinity of the distributors, however, a vertical flow pattern was shown to exist, the vortex decaying rapidly with distance.

Part II. The Influence of Structural Variants on the Disintegration of Varicose Jets -- Ionic solutions, such as potassium carbonate solutions, when sprayed from hypodermic nozzles produced arrays of droplets whose volume- and geometric-mean diameters deviated considerably from empirically based correlations in literature. The volume-mean diameters for organic sprays were found to be dependent more on the dipole moment and molecular configuration of the liquid species than on its physical properties and associated flow variables. Sucrose solutions yielded drops whose diameters were in between those of ionic and organic sprays. In most cases, drop distributions based on number showed bimodal characteristics. Several possible mechanisms are suggested and discussed. For varicose jets of nitrobenzene, the volume-mean drop diameters were found to be only slightly dependent on flowrate. The drop diameter was shown to be sensitive to nozzle diameter. The spread of drop sizes was found to vary with both nozzle diameter and flowrate, increasing with either factor. The available data permitted the calculation of disintegration wave lengths. These were shown to vary slightly with flowrate and/or nozzle diameter. An equation was derived which permits the calculation of the largest population segment of a possible spectrum of droplets from varicose disintegration.

Part III. Studies on the Evaporation of Sprays in Relative Motion to a Concurrent Stream of Hot Air -- The tower spray dryer was used to determine the extent of evaporation of potassium carbonate and nitrobenzene sprays. The liquid nitrogen freezing technique was used to study the pre- and post-evaporation droplet distribution data. The data for potassium carbonate sprays was compared with theoretical predictions for single drops, the surface-mean diameter of the spray being used as a model-drop evaporating under the conditions obtaining for the spray. The experimental data showed higher rates of evaporation than that predicted for the model. The relative shift of the pre-and post-evaporation distribution curves also indicated higher rates of evaporation. It was concluded that droplet oscillation, distortion, acceleration and spin were responsible for the higher rates. Quantitative analysis of the decrease in diameter was not attempted since the primary variables, such as droplet distribution and mean diameter were relatively insensitive to variations in nozzle diameter and liquid flowrate. Droplets much smaller than those of potassium carbonate and more effectively distributed were found to occur in the disintegration of nitrobenzene jets. This liquid was therefore sprayed and the evaporation, as manifested in the shift of the distribution curves, was compared to that predicted for the simultaneous vaporization of discrete sets of droplets. The results of these computations showed the inapplicability of the method to sprays. It was concluded that interactions between droplets and screening effects definitely affect the evaporation rate. The application of this technique to the evaporation of potassium carbonate sprays showed, however, the expected trends.

Microfilm $4.00; Xerox $13.60. 312 pages.

DA 20-3231

A-17. Asatur, K. G., and V. I. Gerontev

Study of Non-Submerged Jets by High-Speed Cinematography (in Russian). K. G. Asatur and V. I. Gerontev. Izvest. Akad. Nauk, SSSR, Otdel tekh. Nauk, 1957, No. 3, pp. 164—167.

Moving pictures were taken at 50,000 frames per sec. of liquid jets ejected at pressures up to 50 atm. As pressure is increased the jet becomes irregular, and finally breaks up; but the velocity of the different portions shows little difference. Velocity for a given pressure is calculated by the Torricelli formula.

deJ II-21

A-18. Asset, G.

"A Solenoid-Operated Microburet for Producing Uniform Droplets," Am. Ind. Hygiene Assoc. J 20, 56 (1959).

A-19. Asset, G. M., and P. D. Bales

"Hydraulic Jets at Low Reynolds Number and Constant Weber Number," Chemical Corps Medical Labs., Army Chemical Center, Maryland. Research Rept. No. [illegible], June 1951.

A-20. Atkinson, W. R., and A. H. Miller
"Versatile Technique for the Production of Uniform Drops at a Constant Rate and Ejection Velocity," Rev. Sci. Instr. 36, 846–7 (June 1965).

B-1. Baljé, O. E., and L. F. Larson

"The Mechanism of Jet Disintegration," Air Material Command, Engineering Division Memorandum Rept. No. MCREXE-664-531B, GS-USAF, Wright Patterson No. 179, August 29, 1949

B-2. Banerjee, T. S., and M. N. Rao

965. Banerjee, T. S., and Rao, M. N., Entrainment of water drops by air bubbles released from a single nozzle, *J. Sci. Engng. Res., India* 6, 1, p. 39, Jan 1962.

Entrainment is the carry over of liquid drops by a gas or vapor which flows through the liquid. This report includes a study of entrainment with respect to drop size and quantity at various Reynolds numbers and submergences. The results obtained reveal a smooth change-over of mechanism from entrainment to two-fluid atomization.

AMR 16-965

B-3. Baron, T.

Atomization of Liquid Jets and Droplets. T. Baron. Techn. Rept. No. 4 (1947) on Contr. N6-Ori-71. Eng. Exp. Sta., U. of Illinois, 24 p., 3 fig., 23 ref.

Treats the instability of jets, chiefly on the basis of Rayleigh's analysis; the mechanism of atomization of liquid jets, following closely Castleman's analysis; and atomization of drops, reviewing Littaye's work, and presenting an alternative analysis. Treats the deformation of a moving drop as forced vibration with viscous damping. In order to be able to oscillate and still not oppose the drag and inertia forces the drop must rotate. The centrifugal forces drive the liquid toward the periphery producing a ring having a thin center membrane which will ultimately be blown out, thus disintegrating the drop into particles of greatly differing sizes. Cites LENARD 1904 as confirming this analysis.

deJ I-21

B-4. Baron, T., and L. G. Alexander

"Momentum, Mass, and Heat Transfer in Free Jets," Chem. Eng. Prog. 47, 181-5 (1951).

Transfer of flux of momentum, mass, or heat in jets from point or finite sources is basic to chemical engineering problems such as the design of combustion chambers, spray dryers, and air atomizers. Equations based on a generalization of Reichardt's hypothesis are derived for the distributions of the fluxes in such jets. These equations are solutions of a differential equation which is linear in the various fluxes. Hence, the distributions from a number of point sources can be superimposed in cases where the boundary conditions can be satisfied. This method has been used to predict the momentum flux distribution adjacent to a finite nozzle with good agreement with experimental measurements. An explanation is given for discrepancies between data obtained by various authors on temperature and concentration distributions in free jets, and the turbulence measurements necessary for comparison with the equations for heat and mass flux are indicated.

Author

B-5. Barret, P.

3796. CONTRIBUTION TO THE STUDY OF ELECTROLYSIS BY SPARK. THE CATHODIC ATOMIZATION OF ELECTROLYTES.
P.Barret.
Bull. Soc. Chim. France, 1956, No. 8-9, 1243-53 (July-Aug.). In French.

An account of a phenomenon observed in the course of an investigation into the production of aerosols using electrical discharges. The phenomenon is the formation of droplets on a platinum wire cathode suspended over the surface of ionized liquids and the atomization of these to form aerosols. A brief description of the apparatus and results obtained is given. A detailed discussion interprets the results and gives a theory of the mechanism of the phenomenon.

PA 60-3796

B-6. Barret, P.

9231* Cathodic Atomization of Fused Electrolytes. (French.) Pierre Barret. *Comptes rendus*, v. 238, no. 10, Mar. 8, 1954, p. 1125-1127.

Compares phenomenon with atomization of dissolved electrolytes. 6 ref.

BMI 3-9231

B-7. Barret, P.

"Dispersion of Electrolytic Solutions by an Anodic Spark." Pierre Barret (Faculté sci., Dijon, France). J. chim. phys. 49, No. 7-8, C57-63 (1952); cf. C.A.46, 3429f.

CA 47-5823 i

B-8. Barret, P.

"Superficial Mechanical Effects in Electrolysis Caused by Sparking." Pierre Barret (Centre recherches sci. ind. maritimes, Marseille, France). J. chim. phys. 49, C194-8 (1952).

CA 46-5465g

B-9. Barret, P.

"Measurement of Flame Temperatures." P. Barret, Pubs. sci. et tech., ministère air (France), Notes tech. No. 33, 42 pp. (1950).

CA 44-8184C

B-10. Beardsley, E. G.

Some Factors Affecting the Reproducibility of Penetration and the Cut-Off of Oil Sprays for Fuel-Injection Engines. E. G. Beardsley. NACA Rept. No. 258(1927) 8 p., 6 fig., 4 ref.

Effects of two types of injection valves, tube length, initial oil pressure, speed of injection control mechanism on the reproducibility of spray penetration and on secondary discharges. Waves initiated by the rapid opening of the cut-off valve. Four photographs are shown of fuel sprays from centrifugal-type nozzles, injected at 8000 psi. into air at densities of 1 to 28 atmospheres. Curves showing the effect of the magnitude and uniformity of the initial pressure in the injection-valve tube, and of the injection tube length, on spray tip penetration. Effect of injection duration, injection tube length, and type of valve on secondary discharges.

de J I-24

B-11. Beardsley, E. G.

The NACA Fuel Spray Photography Apparatus and Test Results from Several Researches. Study of Oil Sprays for Fuel-Injection Engines by Means of High-Speed Motion Pictures. E. G. Beardsley. NACA Rept. No. 274 (1927). 11 p., 12 fig., Trans. ASME Vol. 49/50 (1927–28) OGP-50-3, 9 p., 15 fig.

Description of the NACA apparatus for high-speed photography of sprays. Effect of injection pressure air pressure, fuel density and injection-valve design upon the spray characteristics. Nine photographs of fuel sprays from both plain and centrifugal nozzles are reproduced, showing the effect of chamber-air density and orifice size on the spray characteristics. Injection pressure was 8000 psi in each case; density of the chamber was either 1 or 14.8 atmospheres. Curves are given showing the effects of injection pressure, gas density and specific gravity of the fuel on the penetration of sprays from a plain cylindrical nozzle; other curves show the effects of groove helix angle and ratio of orifice area to groove area on the penetration, distribution and cone angles of sprays from centrifugal type nozzles. Photography at 4000 frames per sec.

deJ I-24

B-12. Benson, G. M., et al.

1128. Benson, G. M., El-Wakil, M. M., Myers, P. S., and Uyehara, O. A., Fluorescent technique for determining the cross-sectional drop size distributions of liquid sprays, *ARS J.* 30, 5, 447-454, May 1960.

Laboratory instrument and procedure for measuring the drop-size distribution of a fluorescent spray are described. A thin sheet of spray is illuminated with a mercury-arc lamp and photographed. Individual drops are then measured. Error in drop-size measurement is about 10% for 10-micron-diameter drops. This indeterminancy decreases rapidly for larger drops, but becomes very great for drops smaller than 5 microns. Authors discuss details of the fluorescent, optical and photographic problems encountered. Size-distribution data and photographs of drops are presented.

AMR 14-1128

B-13. Bently, R. A., J. Cartwright, and R. L. Gordon

"A Photographic Method of Observing the Approximate Size of Liquid Droplets Produced by an Atomizer," Brit. J. Appl. Phys. 4, No. 10, 316 (Oct. 1953).

B-14. Berg, T. G. O., et al.

"Aerodynamic Breakup," pp 47-74 in "Research Study on the Dissemination of Solid and Liquid Agents" Aerojet-General Corp Report No. 0395-04(03)BP, Contract No. DA 18-108-405 CML 829, August 16, 1962

B-15. Bergsøe, C.

"Spray-drying." C. Bergsøe. Mfg. Chemist 20, 72-5 (1949).

CA 45-7831a

B-16. Bergwerk, W.

123 FLOW PATTERN IN DIESEL NOZZLE SPRAY HOLES. W.Bergwerk.

Proc. Instn-Mech. Engrs (GB), Vol. 173, No. 25, 655-60 (1959).

A study is presented of the flow in spray holes of 0.2 to 2.5 mm diameter and shows how the changes in cavitation pattern affect the appearance of the jet. The influence of the cavitation number, Reynolds number, the upstream edge sharpness, and the length/diameter ratio is investigated. A cavity first formed near the upstream corner, but soon caused the jet to leave the wall altogether so that only the upstream corner had any effect on the flow. Under non-cavitating conditions the emerging jet had a ruffled appearance, but under conditions when the jet had left the wall, it emerged smooth and glass-like. The glass-like stage could only be obtained with very accurately made spray holes, and any disturbance upstream, such as occurs in actual Diesel nozzles, caused the jet to appear ruffled at all times. The discharge coefficient was found to vary with Reynolds number and cavitation number and a contour map covering Reynolds number of 1000 to 20000 and cavitation number of 0.2 to 100 is presented.

PA 64-123

B-17. Berneliu, B.

"Simple Apparatus for the Study of Atomization," B. Berneliu (Inst. Franc. Petrole, Rueil-Malmaison, France). Rev. Inst. Franc. Petrole et Ann. Combustibles Liquides 16, 992-7 (1961).

CA 56-57931

B-18. Bete, J. U., and A. C. Neilson

Drop-Size Measurement Methods for Atomizing Nozzles. John U. Bete and Alan C. Neilson (Bete Fog Nozzle, Inc., Greenfield, Mass.). Trade circular (4 p., 4 fig.), and mimeographed brochure (24 p., 15 fig., 2 tabl.), publ. by Bete Fog Nozzle Inc., Greenfield, Mass.

Describes apparatus for measuring drop-size distribution, comprising a sedimentation chamber where a representative sample of the spray is allowed to settle on microscope slides; these are then photographed with suitable magnification and projected on a screen; an electromagnetic caliper is used by the operator to encompass each droplet image; by pressing a pedal switch a counter is actuated representing the drop diameter range. Claims capability of counting and measuring about 200 drops per min., with a high degree of reproducibility.

deJ II-56

B-19. Betz, A., and E. Petersohn

Application of the Theory of Free Jets. A. Betz and E. Petersohn. NACA Tech. Mem. 667 (1932).

Based on Kirchoff's theory of free jets, the flow through different screen arrangements of flat plates as chiefly encountered in the cavitation zone is defined. Experimental verification is given for most cases of discharge of water in air, subsequently by cavitation. Discrepancies are explained qualitatively by the mingling processes between the jets and the dead air zones.

deJ I-29

B-20. Bevans, R. S.

Mathematical Expressions for Drop Size Distribution in Sprays. R. S. Bevans (M. I. T.). Paper at Conf. on Fuel Sprays, U. of Mich., March 1949. 30 p., 7 fig., 7 ref.

The distribution functions by:

Nukiyama-Tanasawa $\frac{dR}{dX} = -2.1 \cdot 10^{4} X^{4} e^{-2.12X}$

Rosin-Rammler $\frac{dR}{dX} = -47.1 X^{1.63} e^{-10.1X^{2.63}}$

and the Logarithmico-Normal $\frac{dR}{dX} = \frac{-1.068}{X} e^{-\frac{(\log x + 0.56)^2}{0.56}}$

are critically examined and all are found to fit the experimental size-distribution data for an oil spray in an acceptable manner, the Rosin-Rammler expression being somewhat superior and having the advantage of being easier to use. Mean drop size may be calculated from any of the three expressions and they agree well among each other. This is not the case for the mean number of drops which, however, is used infrequently.

deJ I-29

B-21. Bezemer, C., and N. A. Schwartz

2191. Bezemer, C., and Schwarz, N., A new equation for the the size distribution of emulsion particles (in Dutch), *Kolloid Z.* **146**, 1/3, 145-151, 1956.

A new equation for describing the size distribution of emulsion particles is presented, termed the "Amsterdam Distribution Equation" (ADE), which is an exponential function having two parameters: the largest droplet diameter, and the size parameter (being the slope of the straight-line graph in a logarithmic diagram). The limits of applicability of this equation have been tested by comparing it with experimental data taken from work of previous experimenters as to: (a) a goodness of fit and (b) agreement as to average diameter.

Comparison is made also with two widely used particle-distribution equations, namely (a) that of Rosin and Rammler and (b) log-probability equation. Reference is made also to the Nukiyama-Tanasawa equation. It is found that the new ADE equation yields closer fit with the experimental data for emulsions than do previously proposed equations. In the discussion it has been pointed out that the Rosin-Rammler equation has been developed primarily for solid particles and not for emulsions. It is also pointed out that all proposed distributions have two maxima, which are probably due to two simple dispersions being present, produced by two different physical mechanisms, e.g., by atomization and condensation in case of liquid sprays.

AMR 11-2191

B-22, Bigg, F. J.

The Atomization of Water by Air Blast Nozzles for the Simulation of Cloud Conditions for Icing Research. F. J. Bigg (Roy. Aircraft Establ., Gr. Brit.). Tech. Note No. Mech. Eng. 203, June 1955, 24 p., 10 fig., 3 tabl., 10 ref.

Research was aimed to produce artificial clouds for icing tests in windtunnels. Review of data on water atomization indicates that air blast nozzles are the only type capable of producing a spray with droplets about 20 micron size, and in the necessary concentrations, for the simulation of natural cloud. Based on size analysis of droplet samples taken from several different air-blast nozzles at various flow rates up to 3 gal./hr., and air pressures form 10 to 40 psi made in a windtunnel with air velocities of 100 to 350 ft./sec., concludes that the volume median diameter of spray droplets, in the range tested is given by the formula:

$$\text{Volume Mean Dia} = 10 + \frac{1.5 \text{ Flow Rate (gal./hr.)}}{\text{Pressure} \times \text{Area of Air Annulus}} \text{ microns.}$$

Formula is given also for air pressure below 10 psi. Notes on design features of the nozzles are included, and also on the degree of preheat of the compressed air to prevent formation of ice crystals in the spray.

deJ II-59

B-23. Biles, M. B.

An Analysis of Short Length Liquid Sprays. M. B. Biles (U. of Calif., Berkeley). Heat transfer and Fluid Mechanics Institute, ASME (1949) pp. 41–50, 36 fig., 6 ref.

Disintegration of short length (intermittent) jets. Despite accurate control of injection conditions, these sprays will not consistently disperse into single particles in a regular fashion, or produce uniform drops. Dispersion and drop-producing mechanism will approach some regularity only when the conditions of injection velocity and jet length permit separation of the entire jet into individual streams. Irregularity of disintegration is greatest when the injection conditions allow both high pressure and low pressure dispersion characteristics to appear in the same jet. Four distinct dispersion processes can be specified under these conditions: separation of the leading surface, compression, waviness and buckling. Varied effect of these processes may aid in explaining the multitude of drop sizes and speeds of drop formation in the dispersion of short length sprays. The descriptions are presented in a qualitative manner in conjunction with fine microphotographs of single jets.

deJ I-31

B-24. Binark, H., and W. E. Ranz

5807. Binark, H., and Ranz, W. E., Quick method for measuring drop size of hollow cone sprays, *Indust. Engng. Chem.* **51**, 5, 701-702, May 1959.

Method consists of establishing an air flow through the spray cone, *at right angle to the latter, whereby the spray droplets are deflected from their direction along the cone to a direction parallel to the cone axis; smaller drops having shorter stopping distance move near the axis, and larger drops having longer stopping distance move far from the axis;* by determining the quantitative distribution across the deflected spray, i.e., perpendicularly to the spray axis, a curve representing the spray flux versus radial distance can be drawn; from this curve, with the additional determination of the initial jet velocity, and using some basic aerodynamic equations *for the motion of small spheres*, the drop-size distribution curve can be plotted. *Experimental apparatus* is illustrated and described; procedure is explained; *motion of a spherical drop* in still gas solely under *influence of aerodynamic forces is given* by equation and is also represented graphically.

AMR 12-5807

B-25. Binark, H., and W. E. Ranz

Simple Test Method for Determining the Drop Size Distribution of a Hollow Cone Spray. Hikmet Binark and W. E. Ranz (Pennsylvania State Univ., University Park, Pa.). Rep. on Contr. Nonr.-1858 (25) Aug. 1958, 15 p., 3 ref. Proj. SQUID Tech. Rep. PSU-2-P.

For hollow-cone sprays, where the induced air flow crosses the crop trajectories, an apparent drop-size distribution can be obtained by considering the stopping distance of various portions of the liquid flux. Simple procedure was developed to demonstrate the relationship between drop size and liquid flux distribution.

deJ II-61

B-26. Binark, H., and W. E. Ranz

Induced Air Flows in Fuel Sprays. Hikmet Binark (Tech. Univ. Istambul, Turkey) and W. E. Ranz (Univ. Minnesota, Minneapolis, Minn.). ASME paper No. 58-A-284, 1958.

Studied the induction of air by hollow-cone, and by solid-cone sprays, in still air. For both types of sprays air flowed perpendicularly to the outside edge of the spray, then turned parallel to the nozzle, once inside the spray. Presents correlations for determining air velocities and mass-flow rates inside hollow-cone sprays, and air velocities outside solid-cone sprays.

deJ II-61

B-27. Binnie, A. M.

The Theory of Waves Travelin[illegible] Core in a Swirling Liquid. A. M. Binnie (Trinity Coll., Univ. Cam[illegible] Engl.). Proc. Royal Soc. (London), Ser. A, Vol. 205, March 1951, pp. 5[illegible]0, 8 fig., 11 ref. (no titl.).

Subject has some [illegible]inency for swirl-type (centrifugal) nozzles. When a swirling liquid passes through a pipe or nozzle, a hollow core is formed. Surface of the core may be continuously disturbed by progressive waves. Presents a mathematical study of waves moving under centrifugal force and surface tension along the core. Waves may be of varicose form in which the cross section of the core remains circular, or they may be helical giving the core the shape of a multi-threaded screw. Relations are obtained between the lengths of the waves and their axial and angular velocities; at a critical length the waves possess a minimum velocity.

deJ II-62

B-28. Binnie, A. M., and D. P. Harris

The Application of Boundary-Layer Theory to Swirling Liquid Flow through a Nozzle. A. M. Binnie and D. P. Harris (Eng. Lab., Cambridge). Quart. Jl. of Mech. and Appl. Math. (Engl.) Vol. 3. Pt. I (1950) pp. 89—106, 7 fig.

Application of critical flow theory to obtain pressure and velocity distribution in the main stream resulting from the passage of a swirling liquid through a convergent-divergent nozzle. Detailed numerical example.

deJ I-31

B-29. Bird, A. L.

Experiments on Oil Jets and Their Ignition. A. L. Bird. Proc. Inst. Mech. Eng. (London) Nov. 1926, pp. 955—995, 18 fig.

Investigation on injection and ignition of oil sprays in a compressed air chamber. Flow through nozzles, penetration, dispersion, globule sizes, ignition temperature and ignition lag. Mathematical analysis of penetration.

deJ I-32

B-30. Bisa, K., K. Birnagl, and R. Esche

2692. Bisa, K., Birnagl, K., and Esche, R., Atomization of liquids by ultrasonics (in German), *Siemens-Zeit.* 28, 8, 341-347, 12 figs. + 12 ref., Sept. 1954.

An ultrasonic aerosol generator for inhalation therapy has been investigated for the influence of the characteristics of the ultrasonic field (frequency, power) on the characteristics of the aerosols produced (droplet size distribution and mean droplet size, and quantity of fog produced), using various liquids. The aerosol generator consisted of a barium-titanate oscillator of concave spherical shape having an included cone angle of about 60 deg, acting upon the liquid and producing a focused ultrasonic field therein. Thereby a high-intensity field is produced at relatively low power. The influence of liquid height on the rate of atomization (cc/min) was investigated for water and for gasoline. The droplet size and fog density were determined for a brine of 5% salt content at frequencies of 1.2, 1.7, 2.7, and 5.4 megacycles at various powers up to 0.6 kilowat; experimental arrangement and curves of results are shown. A chart is given for droplet size distribution of aerosols produced by various methods (by nozzles and by ultrasonics). It was found that the mean droplet size was reduced significantly by increasing the frequency, and reduced (slightly) by increasing the power. The amount of liquid atomize (cc/min) was greater in the case of gasoline (low surface tension) than in the case of water (high surface tension). The experimental results were evaluated as to the influence of cavitation, radiation pressure, surface phenomena, frequency and power of ultrasonic energy input, and efficiency of atomization. The effect of ultrasonic irradiation on macromolecular substances, in particular on antibiotics (aureomycin, digitalis) from the point of their biological effectiveness, is discussed.

AMR 11-2693

B-31. Bitron, M. D.

1713. Bitron, M. D., Atomization of liquids by supersonic air jets, *Indust. Engng. Chem.* 47, 1, 23-28, Jan. 1955.

Paper describes careful experiments on air atomization of a spray of dibutyl phthalate, at supersonic air velocities (from 460 to 680 mps). Air was discharged through one of a series of convergent-divergent nozzles, and the liquid was discharged transversely into issuing air stream. Samples of spray were collected on glass slides and measured under microscope. The slide holder was exposed to spray for only 0.01 sec. Volumetric flow ratio was constant at $Q_l/Q_a = 1.2 \times 10^4$, and loss by evaporation was considered to be negligible.

The results, expressed as Sauter mean diameter, varied considerably from one test to another at nominally same conditions, but, when the results of 10-12 experiments were pooled, the mean droplet size compared well with values calculated from Nukiyama-Tanasawa equation. Variation of air velocity had less effect on mean droplet size than would be expected from this equation, but the author concludes that the Nukiyama-Tanasawa equation is applicable to sprays formed by supersonic gas streams. Work is valuable, and result important, but it should be noted that range of variables was very limited; Sauter mean diameter varied only between 6.7 and 7.3 microns.

AMR 8-1713

B-32. Bittker, D. A.

N64-15219* National Aeronautics and Space Administration
Lewis Research Center, Cleveland, Ohio
EFFECT OF AMBIENT AIR VELOCITY ON ATOMIZATION OF TWO IMPINGING WATER JETS
David A. Bittker. Washington, NASA, Feb 1964 38 p refs
(NASA TN D-2087) OTS $1.00

Drop-size distributions were measured for the sprays formed by two 0.089-in.-diam impinging water jets. Jet impingement angles of 30°, 60°, and 90° and jet velocities of 30

60, and 74 fps were used. These variables were held constant, while the primary variable of this work (i.e., the difference between the ambient air velocity and the liquid jet velocity) was changed from 0 to 120 fps. All distributions show bimodal characteristics with number-median diameters of approximately 200 and 500 microns for the two modes. For low jet velocities, increasing the velocity difference decreases the mass-median diameter of the large-diameter mode and increases the percentages of mass and drops in the small-diameter mode. In the range of velocity difference 0 to 120 fps, the volume-number-mean and mass-median diameters of the complete spray decrease as velocity difference increases, except for the highest jet velocity.

N64-15219, 07-11

B-33. Blanchard, D. C.

A Simple Method for the Production of Homogeneous Water Drops Down to One Micron Radius. Duncan C. Blanchard (Woods Hole Oceanogr. Inst., Woods Hole, Mass.). Jl. Colloid Sci., Vol. 9, No. 4, Aug. 1954, pp. 321–328, 3 fig., 10 ref.

Refers to STUHLMAN 1932. Describes droplet production by bursting bubbles at an air-water interface; collapse of bubble cavity produces an upward moving jet which quickly disintegrates into several small drops; the drops rise to various heights, according to their size, the drops rising to a certain height being very nearly the same size. the drops rising to a certain height being very nearly the same size. Shows photographs of monodisperse drops produced in such manner. The size of the drops is also a function of the bubble size. Refers to WALTON and PREWETT 1949, VONNEGUT and NEUBAUER 1952. Method is usable for producing drops in the size range of 500 to 2 micron diam. deJ II-67

B-34. Blanchard, D. C.

2749. Blanchard, D. C., The behavior of water drops at terminal velocity in air, *Trans. Amer. geophys. Un.* 31, 6, 836–842, Dec. 1950.

Stroboscopic pictures were taken of drops rising slowly in a vertical airstream. Large drops (spherical diameter > 5 mm) show natural oscillations in horizontal plane. Turbulence is effective in breaking up large drops, but both natural oscillations and effect of turbulence are greatly reduced by introducing air bubble within drop. Author concludes that breakup is due to oscillations. Growth of large drops by coalescence is studied; smaller drops were frequently observed to "bounce off" larger drops. Reviewer believes this is a valuable contribution to observational literature. No theoretical discussion of results is given.

AMR 5-2749

B-35. Blinov, V. I.

On the Dispersive Properties of Mechanically Atomized Water (In Russian). V. I. Blinov. VTI, 1931 (Moscow), pp. 1–41, 38 fig., 13 ref.

Methods of measurement of pressure, spray passin; through a unit area in unit time at various positions from axis, cone angle mean drop size, drop-size distribution. Experiments on various nozzles with curves and tables of rate of flow, drop-size distribution, dispersion in space and its variation as a function of distance from nozzle. Theoretical interpretation of results; physics of spray formation; photomicrographs; calculation of period of vibration of a droplet according to Rayleigh's theory; resonance of drop and jet; influence of pressure on drop size.

deJ I-33

B-36. Blokh, A. G., and E. S. Kichkina

"Atomization of Liquid Fuel by Mechanical Centrifugal Sprayers." A. G. Blokh and E. S. Kichkina. Voprosy Aerodinamiki i Teploperedachi v Kotel'no-Topochn. Protsessakh (Moscow-Leningrad: Gosudarst. Energet. Izdatel.) Sbornik 1958, 48-57.

CA 55-7937d

B-37. Bohr, N.

Determination of the Surface Tension of Water by the Method of Jet Vibration. Niels Bohr (Copenhagen, Denmark). Phil. Trans. Royal Soc., London, Ser. A, Vol. 209, 1909, pp. 281–317, 4 fig., 43 equ., 15 ref. (no titl.).

Cited in MIDDLEMAN and GAVIS 1961. Difficulty in determining the surface tension of water is to produce a sufficiently pure surface. In RAYLEIGH 1879B this difficulty was overcome by using the wavelength of a vibrating liquid jet (the surface of which is continuously removed) as basis of determination. In RAYLEIGH 1879B equations were developed under assumptions that the amplitude of oscillation is small, and the viscosity is small. In present work both of these restrictions are removed; presents highly mathematical treatment; calculates effect of finite viscosity, by first, second, and third approximations; calculates effect of surrounding air. Illustrates and describes experimental apparatus, and technique, with painstaking avoidance of contaminating influences. Determined velocity of flow of jet, by cutting through it at constant and known time intervals and photographing the cut-off portion instantaneously; from the distance between two cuts (measured from the photo), and the known time interval, the velocity can be calculated. Gives extensive tabulations of experimental results. Lists previous determinations of surface tension, with names of authors, giving methods, and values found, with comments on each. Finds, as final result, the surface tension of water at 12°C., 73.23 dyne/cm.

deJ II-72

B-38. Bolt, J. A., and T. A. Boyle

3099. Bolt, J. A., and Boyle, T. A., The combustion of liquid fuel spray, *Trans. ASME* 78, 3, 609–615, Apr. 1956.

Burning of liquid droplets of uniform particle size was observed photographically. Particle diameter decreased with time according to equation: $D^2 = D_0^2 - \lambda t$, where D is drop diameter at time t, D_0 is diameter at t equal zero, λ is constant, cm²/sec. Value of λ, using D in cm and t in sec for particles initially about 0.01 cm, is 0.0047 for n-heptane, 0.0046 for n-propyl alcohol, 0.0033 for benzene, and 0.0066 for cyclohexane.

Importance of study lies in measuring rates with many drops, thus simulating combustion-chamber conditions. Value of λ is about one half that obtained by others for larger single droplets suspended on fiber.

Whirling disk was used by authors to obtain the desired uniformity of drop size. Uniformity may be helpful for study and analysis, but reviewer feels some combustion systems perform better with wide spectrum of fuel drop size, as obtains with air atomization. As particles undergo combustion even with initial uniformity, there is an increasing spread of droplet size.

Reviewer agrees with authors' conclusion that problem of combustion is complex.

AMR 9-3099

B-39. Bonch, Ye. I.

Bonch, Ye. I.
HAND-OPERATED PULSATING AEROSOL GENERATORS (Ruchnyye Pul'siruyushcherdye Aerozol'nyye Generatory). 2 Aug 60, 4p. (2 figs. omitted).
Trans. A-1184.
Order from LC or SLA mi$1.80, ph$1.80 60-23160

Trans. of Zashchita Rastenii [ot Vrediteley i Bolezney] (USSR) 1960, v. 5, no. 5, p. 52.

The RAG-1 (Czechoslovakia) and the Swingfog (England and West Germany) are compared and it is announced that the Laboratory of Mechanization of VIZR is completing an experimental model of a modified RAG-1 generator.

T4-368

B-40. Bond, W. N.

The Surface Tension of a Moving Water Sheet. W. N. Bond (Dep. of Phys., Univ. Reading, Engl.). Proc. Phys. Soc. (London), Vol. 47, Part 4, No. 2, July 1935, pp. 549–558, 4 fig., 1 tabl., 4 ref.

Cited in PULS 1936. Direct impact of two equal and opposite cylindrical jets of liquid causes the liquid to emerge radially as a disc in a plane at right angles to the common axis of the jets. The maximum diameter of the disc is a function of the surface tension of the liquid. Developed a method for measuring the surface tension and applied it to water. The liquid surface is renewed 80 times per sec., whereby contamination is prevented. Another method for renewal of surface is the Rayleigh oscillating-jet method. Presents mathematical theory. Illustrates and describes the opposing nozzles and the experimental arrangement. Tabulates the experimental results.

deJ II-73

B-41. Borisenko, A. J.

"The Problem of the Influence of the Turbulence of a Liquid Jet on Its Atomization." Zhur. Tekh. Fiz. 23, 195-6 (1953).

B-42. Borodin, V. A., et al.

Break Up of Liquid Jet Streamlined by a Gas Flux.– Two types of waves propagated along the jet surface studied: tangential waves deforming the jet in the plane of its cross section and leading to its break up into longitudinal fine thin streams, and longitudinal waves. (*In Russian.*) O droblenii strui zhidkosti, obtekaemoi gazovym potokom. – V. A. Borodin, L. N. Britneva, Iu. E. Ditiatkin, and V. I. Iagodkin. *PMTF: Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki*, 1964, no. 5, Sept.-Oct., p. 59-65.

BMI 14-2516

B-43. Borodin, V. A., and Y. F. Dityakin

Unstable Capillary Waves on Surface of Separation of Two Viscous Fluids. V. A. Borodin and Y. F. Dityakin. NACA Memo. 1281 (April, 1951). 19 p., 3 fig.

By considering unstable capillary waves on the surface of separation of two viscous liquids, an attempt is made to provide a mathematical basis for the appearance of drops of different diameters as the result of the breakup of a jet. Assuming the jet as infinitely large in comparison to the lengths of the capillary waves on the surface of the liquid jet, it is possible to study the stability of the plane surface of separation of two infinitely extending viscous fluids and to demonstrate the existence of unstable capillary waves. These waves can lead to the breakaway from the partition surface of several infinitely long strings of fluid of different dimensions. The problem investigated gives an explanation of the disintegration pattern of a liquid jet, without fully explaining the process of atomization.

deJ I-36

B-44. Bose, S.; S. Mukherjee, and J. N. Sharma

"An Improved Glass Atomizer for Paper Chromatography." S. Bose, S. Mukherjee, and J. N. Sharma (Natl. Sugar Inst., Kampur, India). Sci. and Culture (Calcutta) 26, 44 (1960).

CA 55-1096b

B-45. Boshoff, W. H.

Characteristics of a Spinning-Disk Liquid Sprayer. W. H. Boshoff (H. M. Ashanti Colonial Service, Gold Coast, Africa). Inst. Mech. Engrs. Proc., (A), Vol. 166, 1952, pp. 443–446, 4 fig., 2 tabl., 3 equ., 18 ref. (no titl.).

Cited in RYLEY 1954 and 1959 A. Experimented on spinning disc sprayer, to increase output without sacrificing homogeneity of drop-size. Used a 14.25 inch dia. disc; its characteristics were determined by feeding water at various rates centrally onto the disc, varying the disc speed from 600 to 2000 rpm., and noting the resulting drop-sizes and their distribution. Critical flow rate for uniform-size drops was in range of 6 to 22 cc./sec.; size was inversely proportional to disc speed. Product of drop diameter and peripheral velocity of disc is approximately constant and varies with the smoothness of disc surface, rather than with flow rate. Above the critical flow rate homogeneity decreases and a wider range of sizes is observed. Above the flow rate of 110 cu.cm./sec. the liquid leaves the disc in a sheet, with little or no breakup. Reviews past experiments, especially WALTON and PREWETT 1949. Discusses theory of drop formation. Illustrates and describes the apparatus used. Gives detailed tabulation of results (feed rate, peripheral speed, average drop-size).

deJ II-75

B-46. Boucher, R.

2028. **Influence of the ratio of the flow of air and of liquid on the fineness of micronists.** R. Boucher. *C.R. Acad. Sci. [Paris]* 235, 1188-90 (*Nov.* 17, 1952) *In French.*

It is shown that for a certain ratio of flow of air to that of liquid, the fineness of the suspension may be inversely proportional to the air pressure.

PA 56-2028

B-47. Boussinesq, J.

Sur la theorie des nappes liquides retractiles de Savart (On the theory of reconverging liquid sheets of Savart). J. Boussinesq. Compt. Rend. Acad. Sci., Paris, Vol. 157, 15 July 1913, pp. 89–94, 10 equ.

Cited in TAYLOR 1959, and in BUCHWALD and KOENIG 1935, and LANCE and PERRY 1953. Gives detailed mathematical analysis of subject, based on surface tension and hydrodynamic effects.

deJ II-77

B-48. Boussinesq, J.

Théorie des expériences de Savart sur la forme que prend une veine liquide après s'être choquée contre un plan circulaire (Theory of Savart's experiments on the form assumed by a liquid jet after it impinges on a circular disc). J. Boussinesq. Compt. Rend. Acad. Sci., Paris, Vol. 69, pp. 45–48 and 128–131.

Refers to SAVART 1833A. Calculates, on basis of surface tension, the meridional curve of the liquid sheet formed by a liquid jet striking a circular disk. Treatment is largely mathematical. Cited in TAYLOR 1959, and HOPWOOD 1952.

deJ II-76

B-49. Bowen, I. G., and J. R. Joyce

The Effects of Cone Angle, Pressure, and Flow Number on the Particle Size of a Pressure Jet Atomizer. I. G. Bowen and J. R. Joyce (The Shell Petroleum Co. Ltd., London, Engl.). The Shell Petroleum Co., Tech. Rep. ICT/17 (March 1948), 6 p., 11 fig., 5 ref.

Refer to JOYCE 1946, and HOPKINS 1946 describing wax technique of determining spray particle size and the effect of spray cone angle on particle size. Shows that pressure has greatest effect on atomization. Above 30 psi. pressure the effect of cone angle is not pronounced and particle size diminishes with decreasing flow number. At low pressures the effect of cone angle is pronounced, but data are insufficient to determine how this effect is modified by flow number. These conclusions are valid for kerosine with kinematic viscosity of 2 c. s.; it is proposed to extend the investigation to heavy fuels having high viscosity of about 20 c. s. For the type of pressure jet considered the correlation is felt to be adequate for predicting size distribution for combustion application. For atomizers of different design it would be still necessary to determine the size distribution experimentally.

deJ I-37

B-50. Bowen, G., and J. R. Joyce

"Swirl Pressure Jet Atomizers," Tech. Rpt. I.C.T./16 Shell Petroleum Co., Ltd., London, Dec. 30, 1947, 11 pp, 9 figs.

B-51. Brackenridge, J. B.

3657. Brackenridge, J. B., Transverse oscillations of a liquid jet: Part 1, *J. Acoust. Soc. Amer.* 32, 10, 1237-1242, Oct. 1960.

Observations have been made of a thin rectangular jet which issues from an orifice and impinges upon the apex of a rigid wedge which is parallel to the plane of the jet. Such a system displays steady motion or motion corresponding to one of a unique set of ordered oscillatory modes. Which state of motion occurs at a given time depends upon stream thickness, orifice-to-edge distance, stream velocity, kinematic viscosity, and the previous history of the jet. The investigation is divided into two main parts. One deals with the ranges of parameters of the system for which it will execute self-maintained oscillations of a given mode; the other treats frequency characteristics for the different modes. It is found that self-maintained oscillations exist in fluids with a wide range of viscosity. The frequency characteristics are obtained by both optical and acoustical methods; an empirical formula for the frequency is developed.

AMR 14-3657

B-52. Brackenridge, J. B., and W. L. Nyborg

• Transverse Oscillations of a Liquid Jet. II.—A thin rectangular liquid jet impinges on the apex of a rigid wedge and, under suitable circumstances, sets itself into any of a number of modes or "stages" of steady-state transverse oscillation; any mode has associated with it a pattern of vortex production. Excerpts from motion pictures show sequences of jet configurations corresponding to the different modes of oscillation. In a photographic history depicting the building of oscillations in an initially quiescent jet, particular interest is attached to the fact that oscillations appear before vortices have developed. Observations from these photographs and results from an earlier paper are compared with predictions of recent theories of edge tone production.—J. Bruce Brackenridge and Wesley L. Nyborg. *Acoustical Society of America, Journal*, v. 33, Aug. 1961, p. 1078-1084.

EM1 10-10331

B-53. Brown, E. N.

12854 ROTATING BOWL FOR THE PRODUCTION OF UNIFORM DROPS. E.N.Brown.
Rev. sci. Instrum. (USA), Vol. 32, No. 8, 914-15 (Aug., 1961).
Describes a drop generator in the form of a rotating Plexiglas bowl which dispenses large quantities of uniform drops (80-400 μ) with excellent selectivity as to drop diameter.

PA 64-12854

B-54. Brown, H. E., and E. C. Young

Droplet Dispersion Characteristics of Low-Pressure, Disc-Type Nozzles. H. E. Brown and E. C. Young (U. of Texas). Report to Naval Ordnance NOrd-9195, No. CM-618 (1950). 19 p.

Performance data for low pressure disc-type fuel nozzles are presented. Data were obtained by probing Diesel oil sprays in an 8-inch induced-draft air duct. A nozzle (cylindrical jet injector) is described that produces a nearly constant droplet dispersion pattern over a range of air stream velocities (140 – 300 ft./sec.) and over a range of liquid injection rates (0.02 and 0.10 lb./sec.). With the low injection velocities of 5 and 25 ft./sec., the apparent diffusion coefficient varied as the 3/2 power of the disk diameter. Another disk type nozzle ("drooler") for lower injection rates is described.

deJ I-41

B-55. Brown, R. E., and K. L. Leonard

N64-21904 Aerojet-General Corp., Downey, Calif. Research and Engineering Div
METHODS OF DESCRIBING DROPLET-SIZE DISTRIBUTIONS FROM ATOMIZED SOLUTIONS
R. E. Brown and K. L. Leonard 28 Feb 1964 150 p refs
(Contract DA-18-108-405-CML-829)
(Rept.-0395-04(15)SP; AD-434106)
Several mathematical methods were investigated to determine a technique for describing droplet-size distributions produced by pneumatic atomization. The Weibull and log-probability functions have been shown to be reasonably successful in describing these distributions. Data from 43 experiments and the standard deviation of the experimental results from the theoretical curves for both the mass and the frequency distributions are reported. These results show that the Weibull and log-probability functions describe the frequency distribution with the same degree of accuracy, but the Weibull function describes the mass distribution better

N64-21904, 15-23

B-56. Brown, R. and J. L. York

7437. Brown, R., and York, J. L., Sprays formed by flashing liquid jets, *AIChE J.* 8, 2, 149-153, May 1962.

The production of a spray by flashing a liquid jet is seemingly mechanical rather than a function of vapor pressure since it occurs in flow of water at 60 degrees F.

In flow as from "A" the mechanical function is not present. "Broom-tailing" of the jet at a distance from the nozzle, in view of the velocity of the stream probably is a time factor for vaporization upon reaching atmospheric pressure at temperature capable of causing vaporization.

The different "broom tails" shown may represent the difference in pressures in the two cases. Pressure may be critical in point of the nature of the "broom-tail." It is not clear that the two liquids are the same. Varying vapor-pressures may account for the difference.

AMR 15-7437

B-57. Browning, J. A.

"High Energy Atomizer for Fire Extinguishment." U.S. Patent No. 3,033,292, Issued May 8, 1962. Summary: Fire Res. Absts. and Revs. 6, No. 3, 261-2 (1964)

B-58. Browning, J. A.

5240. Browning, J. A., Production and measurement of single drops, sprays, and solid suspensions, New York, Amer. Chem. Soc. (Advances in Chemistry Ser. no. 20), 1958. 136-154.

Experimental investigation of the combustion of sprays is complicated by the many variables involved. Sprays are composed of a wide range of drop sizes distributed unevenly within the spray cone. Turbulence of the air and relative motion of the drops through the air are inadequately defined, yet play an important role in combustion. The burning of an isolated drop presents a difficult problem, which, however, has been clarified to some extent in recent years. To study the effect of any single variable on the combustion of spray, other variables must be kept constant.

This paper reviews spray literature under two main headings: (1) production of drops and sprays, and (2) size measurement of both single particles and sprays (including uniform clouds of drops and solid suspensions).—Under the heading "Production" are treated: single drops and streams of uniform drops and their change through evaporation; spinning disk atomization; pressure atomization; airstream atomization, and impinging jets; aerosol generation; and solid suspensions. Under the heading "Measurement" are treated: mechanical methods including collection on slides, jet impaction, sedimentation, elutriation, centrifugal separation, momentum and mass flow measurement; physico-chemical methods including freezing of drops, evaporation, wax method, thermal precipitation, and gas adsorption; optical methods including photographic and diffraction techniques; electrical methods; size-distribution expressions; particle shape; flow of suspended particles; aggregation of particles; static electrification of dust particles; droplet internal circulation.

For all these headings and subheadings the most important recent literature is cited.

AMR 11-5240

B-59. Brun, R. J., J. Levine, and K. S. Kleinknecht

310. Brun, R. J., Levine, J., and Kleinknecht, K. S., An instrument employing a coronal discharge for the determination of droplet-size distribution in clouds, *Nat. adv. Comm. Aero. tech. Note* 2458, 53 pp., Sept. 1951.

Size distribution of droplets, in clouds above freezing temperatures, is measured by charging droplets in an electric field and allowing them to impinge on collecting cylinders of different diameter. The droplets are separated, according to mass, by flow around the larger cylinders. The charge deposited on each cylinder is a measure of the size distribution, when the collection efficiency is known.

A derivation is given of the electric field equation used and of the rate of acquisition of charge by water droplets. A flight instrument used to evaluate the method indicated required improvements in technique.

AMR 5-310

B-60. Brun, R. J., et al

Brun, R. J., Lewis, W., Perkins, P. J., and Serafini, J. S., "Impingement of Cloud Droplets on a Cylinder and Procedure for Measuring Liquid-Water Content and Droplet Sizes in Supercooled Clouds by Rotating Multicylinder Method," NACA Rep. 1215 43 pp., 1955.

B-61. Brun, R. J., and H. W. Mergler

3261. Brun, R. J., and Mergler, H. W., Impingement of water droplets on a cylinder in an incompressible flow field and evaluation of rotating multicylinder method for measurement of droplet-size distribution, volume-median droplet size, and liquid-water content in clouds, *NACA TN* 2904, 71 pp., Mar. 1953.

Evaluation of the rotating multicylinder method for the measurement of droplet-size distribution, volume-median droplet size, and liquid-water content in clouds show that small uncertainties in the basic data eliminate the distinction between different cloud droplet-size distributions and are a source of large errors in the determination of the droplet size. Calculations of the trajectories of cloud droplets in an incompressible air flow field around a cylinder were performed on a mechanical analog constructed for the study of the trajectories of droplets around aerodynamic bodies.

Matching curves for obtaining droplet-size distribution, volume-median droplet size, and liquid-water content from flight data were computed from the results of the droplet-trajectory calculations. An evaluation is presented of the rotating multicylinder method for the measurement of droplet-size distribution, volume-median droplet size, and liquid-water content in clouds. Because of the insensitivity of the multicylinder method to changes in conditions in clouds, and the inaccuracies in obtaining flight data, errors as large as 70% in the determination of the volume-median droplet size are possible if the flight speed is 200 mph and the actual volume-median droplet diameter in the cloud is 30 microns.

AMR 6-3261

B-62. Bruniak, R., and F. Magyar

"Nozzles for the Atomizing of Liquids." R. Bruniak and F. Magyar (Tech. Hochschule, Vienna). Radex Rundschau 1952, 120-3.

CA 47-924h

B-63. Buchmann, S. W.

2692. Buchmann, S. W., An experimental investigation of drop disintegration (in Russian), ***Vestnik Akad. Nauk KazSSR.*** **no. 11, 80-87, 1955;** ***Ref. Zh. Mekh.*** **no. 11, 1956, Rev. 7449.**

The experimental method and results are presented of an investigation of the process of disintegration of liquid drops in an air-stream.

The drops are photographed by stroboscopic illumination, enabling both the velocity and the instant of disintegration to be determined.

The experiments were conducted with drops of approximate spherical shape measuring $1.39 \leqslant d \leqslant 2.98$, run in a range of flow velocities between $8.4 \leqslant \omega \leqslant 11.35$ mps.

In the author's opinion, calculation of the fragmentation factor of the drops requires taking into account the velocity of the particle at the instant of disintegration.

The numerical value of the factor is found to be influenced by turbulence in the flow.

The values of the fragmentation factor obtained in the experiments diverge considerably from the values previously determined by other authors. [Prandtl: "Hydro-Aerodynamics," Foreign Literature Publishing House, 1951; M. S. Volynsky, *Doklady Akad. Nauk SSSR* **68**, 2, 237-240, 1949; A. S. Zverev, B. V. Kiryukhin, and others, "Textbook of meteorology," Tver Hydro-Meteorological Publications, 1951.]

AMR 11-2692

B-64. Bukhman, S. V., and A. P. Chernov

4279. Bukhman, S. V., and Chernov, A. P., Investiga on binary-phase free jets (in Russian), Issled. Fiz. Osnov. Prots. Topok i Pechey, Akad. Nauk KazSSR, Alma-Ata, 1957, 175-189; ***Ref. Zh. Mekh.*** **no. 4, 1959, Rev. 4031.**

The first part discusses the phenomena of breakdown of droplets of different liquids (water, ethyl alcohol, glycerine, toluene) in air. The experiments on the disintegration of droplets were by spark photography of freely-falling droplets of the different liquids, while breaking up in a stream of air. The mechanism of droplet disintegration has been investigated. It has become evident that in determining the numerical value of the disintegration constant, attention must be paid to the turbulence characteristics of the stream (jet) in which the droplets are broken up (atomized). It is demonstrated that for a laminar flow the value of the disintegration constant (coefficient of atomization) is approximately 3.5. Experimental proof is given that the value of the coefficient of atomization does not depend on the velocity of the droplet, but rapidly decreases with increasing degree of turbulence of the flow. The second part of the paper presents the results of experimental investigations on the motion of solid particles in a free jet. A method of calculating the velocities of such solid particles is presented. It is shown that in dust-laden, free-air jets, the velocity of the particles of the solid phase, varies considerably from the velocity of the air stream—even with particles of relatively small dimensions, of the order of 50-70 μ. The relative velocity of the particles in the jet is proportional to their size and initial velocity and inversely proportional to the density and viscosity of the gaseous medium in the jet, the radius of the nozzle from which the jet issues, and the form coefficient of the particles. It is made evident that the ratio of the particle velocity to the air velocity in corresponding parts of the starting length of the jet is approximately a constant. Authors are of the opinion that the rotation or spinning of the particles in the jet is essentially due to collisions and rolling on the walls of the nozzle, as well as the velocity gradients across the air flow, and the irregular shape of the particles. It has been shown experimentally that the drag coefficient of particles of irregular shape is higher than the drag coefficient of a sphere. An empirical relationship is put forward for determining the drag coefficient of a particle of irregular form by means of the drag coefficient for a sphere.

AMR 14-4279

B-65. Buki, I.

"Heat Transfer in Liquid Atomizers. II. Imre Buki (Tech. Univ., Budapest, Hung.). Energia Atomtech. 15, 145-51 (1962).

CA 57-8390a

B-66. Burdette, R. C.

"Some of the Principles Governing the Production of Air-Floated Oil Particles and their Relation to the Toxicity of Contact Oil Sprays to Insects," New Jersey Ag. Expr. Sta., New Brunswick, N. J., Bull. 632, 31 pp. Jan. 1938

B-67. Burton, E. F., and W. B. Wiegand

"Effect of Electricity in Streams of Water Drops," Phil. Mag. 23, 148-65 (1912)

B-68. Burton, E. J., and J. R. Joyce

1342. Burton, E. J., and Joyce, J. R., Measurements of the size of droplets from convergent-divergent nozzles used in oil burners for steel furnaces, ***J. Inst. Fuel*** **30, 198, 395-398, July 1957.**

The size distribution by weight of droplets from an oil burner, designed to give the maximum forward thrust, has been measured for two nozzles at fuel flows from 70 to 300 lb/h with atomizing air-to-fuel ratios ranging from 0.7 to 1.7 lb per lb (5 to 12 lb per gal). The method used was to replace the heavy fuel oil by blended wax having the same viscosity, and to analyze the resulting spray of wax droplets which freeze in flight. The results showed that, except at the lowest flow rate, the median size ranged from 47 to 70 micron, which values are comparable with those from typical steelworks burners. The relevant spray parameters at each flow rate are given in the paper. Neither the nozzle profile nor the distance of the fuel pipe from the nozzle entrance had an appreciable effect on the size distributing. Two convergent-divergent nozzles were used, designed for atomization by steam, but in these tests they were used with compressed air: throat diameter 0.375 in. The test equipment was an improved version to that used previously by Joyce. Photographs of droplets are shown for each nozzle, and for various fuel flows (40, 20, and 10 gal/h) and air flows (240 to 50 lb/h). Particle-size distribution is given in charts, for each nozzle.

AMR 11-1342

B-69. Byutner, E. K.

N65-14259# Joint Publications Research Service, Washington, D.C.

DEPENDENCE OF DISPERSION OF PARTICLES EMITTED BY A CONTINUOUS SOURCE ON THE DURATION OF THE EXPERIMENT

E. K. Byutner 11 Jan. 1965 13 p refs Transl. into ENGLISH from Tr. Gl. Geofiz. Observ. (Leningrad), v. 150, 1964 p 78-84

(JPRS-28221; TT-6530102) OTS: $1.00

An expression was derived for a finite interval for the mean dispersion of particles emanating from a continuous source. The dispersion is dependent not only on the Lagrange correlation function of particle velocity, but also on the correlation between the velocities of particles emitted one after the other at the interval τ from the source and carried for different times in the turbulent field. It is shown that the formula for dispersion obtained by Ogura is incorrect.

N65-14259, 04-23

C-1. Cadle, R. D.

"Particle Size, Theory and Industrial Applications," Reinhold Pub. Corp., New York, 390 pp, 1965.

C-2. Cadle, R. D.

"Particle Size Determination." Interscience Publishers, New York, 1955

C-3. Cahn, J. W.

9432 STABILITY OF ELECTRICALLY CHARGED CONDUCTING DROPLETS. J.W.Cahn.
Phys. of Fluids (USA), Vol. 5, No. 12, 1662-3 (Dec., 1962).
Calculations are made to show that an electrically charged sphere becomes metastable when the ratio of electrostatic to surface energy is in excess of 0·7.

PA 66-9432

C-4. Carson, R. S.

N65-12023# Illinois U., Urbana Charged Particle Research Lab.
ELECTRICAL SPRAYING OF MACROSCOPIC LIQUID PARTICLES UNDER PULSED CONDITIONS
Ralph S. Carson 15 Jan. 1964 56 p refs
(Grants NSF G-19776; AF-AFOSR-107-63)
(AFOSR-64-1470; AD-604428)

It was found that glycerine, Octoil, and Octoil doped with tetra-n-butylammonium picrate readily spray from the end of a fine capillary, maintained at a high dc potential, in short periodic bursts that continue over a prolonged time interval of at least several hours. The dependence of the naturally pulsed spraying on applied voltage, on liquid constants and pressure, and on the geometry of the apparatus is determined by observing the spraying current; typical results are given. New techniques are presented for determining the specific-charge spectra of the droplets emitted in selected intervals during the spraying pulses by time-of-flight mass spectrometry, and for taking photomicrographs of the liquid surface at any instant before, during, and after the spraying pulses. A method for synchronizing the spraying to an external pulser is indicated.

N65-12023, 02-28

C-5. Castleman, R. A.

Mechanism of Atomization Accompanying Solid Injection. R. A. Castleman, Jr. (Bu. of Standards, Washington, D. C.) NACA Rept. No. 440 (1932) 12 p., 9 fig.

Review of theoretical and experimental investigations by Kuehn, Triebnigg, Sass, Woeltjen, Castleman, Haenlein, DeJuhasz, Joachim and Beardsley, Lee and Spencer, Rothrock, and Bird on the atomization of liquids by solid injection. Concludes that solid injection atomization is similar to air-stream atomization, being due to the formation, at the gas-liquid interface, of fine ligaments by the relative motion of gas and liquid, and to their collapse, under the influence of surface tension, to form drops.

deJ I-52

C-6. Castleman, R. A.

The Mechanism of the Atomization of Liquids. R. A. Castle[illegible] Jl. of Res. (Natl. Bur. Stds.) Vol. 6 No. 281 (1931) pp. 369–376, 5 fig.

Discussion of general problem and some applications of liquid atom[illegible]n. Summarizes work of Plateau and Rayleigh and further expands the atomization [illegible]ry with special reference to spray phenomena in a carburetor, i.e., atomization in an [illegible] stream. Formation of spray is described as tearing off of ligaments from the surface [illegible] the jet by air friction, and collapse of ligaments due to surface tension.

deJ I-52

C-7. Castleman, R. A.

The Influence of the Degree of Instability on the Phenomena of Round Liquid Columns. R. A. Castleman, Jr. (Bu. of Standards, Washington, D.C.) Nature (London), Vol. 114 (1924), No. 2876 pp. 857–858.

Summary of the work of others and some observations of the author on collapse of round liquid columns. (See CASTLEMAN 1931).

deJ I-51

C-8. Chadeyron, S., A. Combe, and H. Guenoche

"Sur la Methode Microphotugraphique d'Observation des Jets-Pulverisées." Rev. Institut Francais du Petrole 12, no 2, 240-7 (1957).

C-9. Chaikin, S. W., and A. C. Wilbur

"Generator for Low Concentrations of Aerosols." Saul W. Chaikin and Arthur C. Wilbur (Stanford Res. Inst., Menlo Park, Calif.). Chemist-Analyst 49, 52 (1960).

CA 57-2011h

C-10. Chamberlin, J. C., et al.

1241. Chamberlin, J. C., Gotzendaner, C. W., Hessig, H. H., and Young, V. D., Studies of airplane spray-deposit patterns at low flight levels, U. S. Dept. Agric., Agric. Engng. Res. Branch, Tech. Bull. 1110, 45 pp. + 29 figs. + 5 ref., May 1955.

Study of spray-deposit patterns of insecticide and pest control media from a low-flying airplane, fitted with an underwing boom carrying evenly placed spraying nozzles, concerns: (a) patterns of spray from individual 1-ft segments of underwing and tail booms with respect to aerodynamic forces that affect them; (b) effect of spray atomization on the consistency of deposit rates, especially in the zone affected by the propeller vortex; (c) arrangement of nozzles, both with regard to atomization and spacing, required for optimum pattern and swath width.

A carmine dye was used as a tracer in the sprays; the spray deposits were collected on stainless-steel plates and measured by colorimetric analyses. Movies were taken during application to show development of spray curtain as it was affected by air currents generated by the airplane flight. Effective swath widths were determined by practical field tests on insect control. It was found that even though the spray is discharged in equal amounts from evenly spaced nozzles, yet aerodynamic forces greatly influence the deposits from foot to foot, both across and along the line of flight. At low flight levels the spray is spread laterally over a swath from 20 to 50 ft wider than the boom, depending on the height of flight, the fineness of the spray, and the presence of surface winds. The deposit pattern within the propeller slipstream zone is erratic.

Improvement in mean spray-deposit rates across a treated swath may be obtained from asymmetrical nozzle arrangements, the use of finer sprays inboard than outboard, and by using moderate rather than low flight levels.

AMR 11-1241

C-11. Chandrasekhar, S.

A65-25441 #
THE STABILITY OF A ROTATING LIQUID DROP.
S. Chandrasekhar (Chicago, University, Chicago, Ill.).
Royal Society (London), Proceedings, Series A, vol. 286, May 25, 1965, p. 1-26. 15 refs.

Investigation of the stability of a rotating drop held together by surface tension, utilizing an appropriate extension of the method of tensor virial. Consideration is restricted to axisymmetric figures of equilibrium which enclose the origin. These figures form a one-parameter sequence; and a convenient parameter for distinguishing the members of the sequence is $\Sigma = \rho\Omega^2 a^3/8T$, where Ω is the angular velocity of rotation, a is the equatorial radius of the drop, ρ is its density, and T is the interfacial surface tension. It is shown that $\Sigma < 2.32911$ (not $1 + \sqrt{2}$ as is sometimes supposed) if the drop is to enclose the origin. It is further shown that with respect to stability, the axisymmetric sequence of rotating drops bears a remarkable similarity to the Maclaurin sequence of rotating liquid masses held together by their own gravitation. Thus, at a point along the sequence (where $\Sigma = 0.4587$) a neutral mode of oscillation occurs without instability setting in at that point (i.e., provided no dissipative mechanism is present); and the instability actually sets in at a subsequent point (where $\Sigma = 0.8440$) by overstable oscillations with a frequency Ω. The dependence on Σ of the six characteristic frequencies, belonging to the second harmonics, is determined.

A65-25441, 15-12

C-12. Chemical Research and Development Laboratories

AD-205 196 Div. 3

Chemical Warfare Labs., Army Chemical Center, Md.
SYMPOSIUM VIII. VOLUME I. SPRAY DISSEMINATION OF AGENTS, CONDUCTED BY U.S. ARMY CHEMICAL WARFARE LABORATORIES 4, 5 and 6 MARCH AT ARMY CHEMICAL CENTER, MARYLAND. July 58, 158p. incl. illus. table (CWL special pub. no. 2) **Unclassified report**

Contents:
Principle of balanced stresses and the mechanical formation of aerosols, by W. E. Ranz
Breakup of liquid droplets, thickened and unthickened, by James D. Wilcox
The aerodynamic breakup of droplets, by John W. Corcoran
Impaction efficiency of aerosol particles, by S. J. Magram
Evaporation of liquid droplets falling a cloud, by Albert Pfeiffer
Travel of droplets in turbulent stream, by Gabrielle Asset
Models for computing contamination expected from aircraft spray, by John Rosinski, Richard H. Snow, and Fred B. Smith
Techniques for the determination of droplet sizes in spray, by A. L. Woolridge
Development of a camera to photograph high-speed particles, by John A. Brackley and associates
Dispersion vs diffusion processes, by William G. Tank
(See also AD-115 835, AD-304 460)

TAB U59-8

C-13. Chemical Research and Development Laboratories

AD-304 460 Div. 3/1, 3/7

Chemical Warfare Labs., Army Chemical Center, Md.
SYMPOSIUM VIII. VOLUME II. SPRAY DISSEMINATION OF AGENTS, CONDUCTED BY U. S. ARMY CHEMICAL WARFARE LABORATORIES 4, 5, 6 MARCH 1958 (Unclassified title). July 58, 240p. incl. illus. tables (CWL Special pub. no. 2)
Secret report

TAB U59-9

C-14. Chen, T. -F., and J. R. Davis

3826. Chen, T.-F., and Davis, J. R., Disintegration of a turbulent water jet, *Proc. Amer. Soc. Civil Engrs.* **90, HY 1** (*J. Hydr. Div.*) (Part 1), 175-206, Jan. 1964.

Paper studies the mechanics of break-up of a turbulent waterjet, issuing into still air from straight pipes and sharp-edged orifices, simulating sprinkler irrigation systems.

From the jet exit to the initial break-up point, the initial disturbance of the jet due to turbulence in the fluid and surface tension forces were the predominant factors affecting the disintegration of a turbulent jet. The mean characteristics of the jet, namely the surface disturbance, jet length and initial drop size were studied in detail by high-speed photography, formulated by dimensional analysis and expressed in terms of Weber and Reynolds numbers.

AMR 18-3826

C-15. Cheng, S. I., and J. Cordero

3014. Cheng, S. I., and Cordero, J., Droplet formation from a liquid film over a rotating cylinder, *AIAA J.* **1, 11,** 2597-2601, Nov. 1963.

Paper concerns the problem of atmospheric contamination when a re-entering radioactive body (e.g. satellite reactor) is ablated, the molten surface layers being shed as droplets. Authors contend that the accelerative regime then obtaining justifies analogy with the case of liquid flung off the surface of a rotating cylinder, a system amenable to laboratory study. The study confirms the well-established formula of Walton [*Proc. Phys. Soc.* (B) 62, 341-350, 1949] for drop size from this type of system and concludes that drops of 1-2 mm will be formed. Reviewer feels that the effects of aerodynamic dilatation of the molten layer, not considered in the present paper, would be of overriding importance.

ARM 17-3014

C-16. Chevalerais, G., and R. Kling

"Atomization and Combustion in a High-Speed Air Stream." Recherche Aéronaut. No. 58, 9-16 (1957).

Le problème de la pulvérisation et de la combustion d'un carburant liquide, tel qu'il se présente dans une chambre de rechauffe de turboréacteur ou dans une chambre de statoréacteur, est étudié.

Après une analyse succincte des processus qui interviennent depuis l'injection du carburant jusqu'à la combustion complète, l'appareillage utilisé pour les essais est décrit.

L'analyse de la pulvérisation par la microphotographie ultra-rapide a permis de déterminer la répartition des gouttelettes dans la veine d'air et de préciser l'influence sur la distribution de certains paramètres (vitesse de l'air, distance à l'injecteur). La structure du brouillard en l'absence de flamme est comparée à celle observée avec combustion.

Author

C-17. Chih-En, G.

A note on the charge produced by spraying liquids with a jet of air. Chih-En, G. *Phil. Mag.*, 36, pp. 218-219, *March*, 1945.—The charge is calculated on the assumption that it arises from the change in surface tension produced when a drop, of radius R, breaks up into a large number of smaller drops. If the charge on each small drop is q it is shown that $q^2 \propto R^3$.

PA 48-3013

C-18. Choudhury, A. P. R.

SIZE DISTRIBUTION OF DROPLETS FROM GROOVED CORE CENTRIFUGAL PRESSURE NOZZLES

(Publication No. 19,060)

Amarendu Prosad Roy Choudhury, Ph.D.
Northwestern University, 1956

Supervisor: William F. Stevens

This study was directed toward the prediction of the size distribution of droplets from grooved core centrifugal pressure nozzles and an understanding of the mechanism of atomization. The experimental technique consisted of capture of the high velocity liquid droplets in a liquid nitrogen bath and subsequent screening of the resulting frozen spheroids into suitable size fractions inside a cold room operated at a temperature below the melting point of the material sprayed. The size fractions were weighed outside the cold room in a normal environment, after allowing the frozen droplets to melt inside a dessicator. This method of temperature equalization minimized condensation of moisture and thereby provided a reasonably accurate computation of weight fractions.

The liquid nitrogen droplet collecting technique was found to be quite satisfactory for studying the size distribution of drops. The results indicated that the size distribution of droplets is a direct outcome of the interplay of three major forces. These forces are (a) Inertia forces, (b) Viscous forces, (c) Surface forces. The different physical properties such as viscosity, density and surface tension are indirect factors in atomization. These properties influence the magnitude of the forces which in turn determine the size distribution. The complex phenomena of droplet formation is inherently unstable. The mode in the frequency curve travels at random over a size range. With time this averages itself to give a mode over a preferred size as determined by the interplay of the three major forces previously mentioned. Factors hindering atomization tend to increase the degree of non-uniformity of a spray, for example, for low Reynolds number frequency curves with more than one mode were obtained.

The size distributions of droplets were based on the experimental measurement of mass on each size fraction. A square root normal distribution was found to fit the data best. This choice of distribution was also influenced by the mathematical simplicity of the function itself and the ease of manipulation of the function in computations. In order to characterize the function completely, the first and second statistical moments were correlated in terms of easily available physical and dynamical variables. The correlation was general in nature and was based on the following postulates:

1. $$\left(\frac{\partial EX^{\frac{1}{2}}}{\partial N_{Re}^{2}}\right)_p = f(N^{\frac{1}{2}}_{Re})$$

2. $$\frac{I}{\left(\frac{\partial EX^{\frac{1}{2}}}{\partial N_{Re}^{2}}\right)_p} = g(Z^{\frac{1}{2}})$$

where

$\left(\frac{\partial EX^{\frac{1}{2}}}{\partial N_{Re}^{2}}\right)_p$ = slope of the line obtained from $EX^{\frac{1}{2}}$ vs. N_{Re}^2 plot at any pressure p.

$EX^{\frac{1}{2}}$ = Expected value of the random variable $X^{\frac{1}{2}}$.

I = Intercept of the Line $EX^{\frac{1}{2}}$ vs. N_{Re}^2

f, g = functional notations.

With the ordinate at zero Reynolds number a similar procedure was followed for correlation of $X^{\frac{1}{2}}_{15.87}$ and log EX. Now knowing $EX^{\frac{1}{2}}$ and $X^{\frac{1}{2}}_{15.87}$ the distribution may be completely characterized. Also, a quick method of estimation of the expected value, EX, of the spray was outlined. This method is general in nature and is expected to hold for centrifugal pressure nozzles, within the injection pressure range of 15 lb./sq. in. to 100 lb./sq. in..

In general it was found that the square root normal distribution gives a satisfactory fit to the experimental data, and that a realistic correlation may be obtained relating size distribution parameters to appropriate ratios of the three major forces. 281 pages. $3.65. Mic 57-3586

DA 17-2229

C-19. Cizinsky, V., and J. Kolousek

5755. Cizinsky, V., and Kolousek, J., Ultra-centrifuge as aerosol generator and its practical and scientific application (in Russian), *Kolloid. Zh., USSR* 21, 6, 739–746, 1959.

This ultra-centrifuge comprises a funnel-shaped stator with entry nozzles *for the driving air*, and a conical rotor with channels against which the entering air impinges; high-pressure air is supplied through a hose. With 10-atm supply air, about 200,000 rpm is attained; for inhalation purposes about 75,000 rpm is used. The atomizing disk has about 1-inch diameter; to it is fed the medicine to be atomized, at a rate of about 2 cu cm per min. The coarse drops are sedimented out; the fine droplets enter the room air; droplet size is regulated by altering the disk speed. Authors describe a bactericidal test using penicillin.

AMR 14-5755

C-20. Clare, H., and H. Radcliffe

2306* An Air-Blast Atomizer for Use With Viscous Fuels. H. Clare and A. Radcliffe. *Institute of Fuel, Journal*, v. 27, Oct. 1954, p. 510-515.
Description and performance of atomizer; fuel and air flow; particle size. Diagrams, graphs.

BMI 4-2306

C-21. Clutter, D. W.

"Mass and Number Distribution of Aeroprojects Ultrasonic Generator Bishop Jet No. 3," Chem. Corps Biol. Labs, Fort Detrick. Interim Report No. BLIR-45, Dec. 1953.

C-22. Cohen, E.

N64-27961 Space Technology Labs., Redondo Beach, Calif.
RESEARCH ON CHARGED COLLOID GENERATION Final Report, Apr. 1963–Mar. 1964
E. Cohen Wright-Patterson AFB, Ohio, AF Aero Propulsion Lab., Jun. 1964 112 p
(Contract AF 33(657)-10999)
(APL-TDR-64-76; AD-601390)

The experimental research involved in the electrical-dispersion-of-liquids technique of generating a charged colloid beam is described. Charge-mass ratios were obtained by using a quadrupole focusing mass spectrometer during the single capillary tube stage of the work. When multiple needles were operated in parallel to increase the beam current, time-of-flight measurements replaced the quadrupole spectrometer. Data are presented both for the results obtained with single capillary tube operation and for the operation of many tubes in parallel.

N64-27961, 20-07

C-23. Cohen, L.

"Survey of Spray Dissemination of Thickened Liquids," pp 111-116 in "Spray Dissemination of Agents," Report of Symposium VIII, Vol. II. Conducted by U.S. Army, CWL March 4-6, 1958. SECRET

AD 304 460

C-24. Cohen, N., and M. Webb

N62-12028 Guggenheim Labs. for the Aerospace Propulsion Sciences, Princeton, N. J.
EVALUATION OF SWIRL ATOMIZER SPRAY CHARACTERISTICS BY A LIGHT SCATTERING TECHNIQUE.
Norman Cohen and Maurice Webb. Feb. 8, 1962. 75 p. 9 refs. (Aeronautical Engineering Lab. Rept. 597) (Contract AF 49(638)-938)

The Sauter mean diameter of the droplets produced by a swirl-type atomizer was measured over a wide range of injector pressure drop, ambient gas density, and ambient gas viscosity. The measurements were made employing the optical (light scattering) technique developed at Princeton by Dobbins. The Sauter mean diameter was found to decrease with increasing values of pressure drop to a certain minimum, after which it began to increase slightly. It was found to increase with increasing ambient gas density to a certain maximum, after which it began to decrease. This latter effect seemed to depend on the kinematic viscosity of the ambient gas. Thus, the effect of the ambient gas dynamic viscosity was to determine the value of ambient gas density at which this maximum (also appearing as a branching from the main density effect) would occur. No similar correlation was found with respect to the value of pressure drop at which the Sauter mean diameter reached a minimum. The effect of the ambient gas density and of the injector pressure drop seemed to be more important than that of the ambient gas Reynolds number, as the latter exhibited only a weak dependency.

These results are qualitative as no simple law appeared to hold in either case, even in the regions before the reversal in trends took place. The fact that no simple law was followed reflects the complexity of the atomization process. The purpose herein was to extend the regions wherein these studies have been made previously by employing a new technique. In the overlapping regions, there was agreement with other investigations with respect to the effect of pressure drop. However, with respect to the effect of ambient gas density, there was agreement with some and disagreement with others. Agreement did exist in that the ambient gas dynamic viscosity had a negligible effect in those regions. It was established that the light scattering technique could be conveniently applied to droplet measurements.

N62-12028, 06-24

C-25. Colburn, A. J., and H. H. Heath

"Swirl Atomizer Sprays in Partial Vacuum," National Gas Turbine Establishment, Memo. 86, May 1950.

C-26. Collacott, R. A.

"Impact of Drops - Photographic Record of Disintegration," Engineering <u>187</u>, 440-1 (April 3, 1959).

C-27. Comings, E. W.

Atomization and Mixing of Fluid Streams. E. W. Comings (U. of Illinois). Summaries and abstracts of papers given at the meeting on Fundamentals of Combustion, Appl. Physics Lab., Johns Hopkins U., (1947). pp. 11–13.

Review of various drop-size distribution formulae. Discussion of atomization in a moving gas stream and equipment for study of mixing of gas streams.

deJ I-55

C-28. Comings, E. W., C. H. Adams, and E. D. Shippee

High Velocity Vaporizers. E. W. Comings, C. H. Adams, and E. D. Shippee. Ind. Eng. Chem., Vol. 40 (1948), pp. 74–76, 2 fig., 6 ref.

Description of a vaporizer in which the liquid is introduced at the throat of a venturi through which hot gas flows at high velocities ranging from 500 to 1800 feet per second. The liquid is atomized to drops of less than 100 microns; the high rate of heat transfer gives rapid vaporization while the hot gases are cooled, thus permitting evaporation of thermally unstable liquids. Developed for smoke generators.

deJ I-55

C-29. Consiglio, J. A., and C. M. Sliepcevich

2690. Consiglio, J. A., and Sliepcevich, C. M., Effect of liquid physical properties and flow rates on the surface area of sprays from a pressure atomizer, *AIChE J.* 3, 3, 418-427, Sept. 1957.

The title problem was investigated experimentally; the specific surface area of the sprays is correlated by an equation of two dimensionless groups in terms of the variables: (a) surface tension to the −1.0 power, (b) kinematic viscosity to the −0.4 power, and (c) volume flow rate to the 2.4 power. The volume flow rate is correlated by an equation of two dimensionless groups containing the variables: (a) viscosity to the 0.17 power, (b) density to the −0.58 power, and (c) spray pressure to the 0.42 power. The conversion of compression energy to surface-area energy appears to be constant at approximately 0.1%. An optical sampling method is used based on the light-scattering properties of spherical particles. The method consists of measuring continuously the intensity of a transmitted light beam through a dispersion of droplets as they settle differentially under the influence of gravity through a known settling distance. The size distribution of the spray is calculated from the light-intensity measurements by means of a modified form of the Lambert-Beer transmission equation, and the Stokes Law. The technique is restricted to drops of less than 40-micron diam. Method of calculation, tables of numerical data, and their graphical representation are explained and given in detail. Attempt was made to check the surface-area values by means of high-speed photographic technique but it was not successful owing to the high velocity of the droplets issuing from the nozzle.

AMR 11-2690

C-30. Corcoran, J. W.

Aerosol Distributions and the Aerodynamic Breakup of Droplets. John W. Corcoran (Beckman and Whitely, Inc., San Carlos, Calif.). Instrument Soc. of Am., Conference Preprint No. 12-SF60, Automation Conf., San Francisco, Calif., May 1960. 11 p., 14 fig., 4 ref.

Discusses number of parameters necessary to define an aerosol; shows that starting with the four-parameter Nukiyama-Tanasawa function, by assigning specific value to the exponent parameter, the Rosin-Rammler function is obtained, of which graphical representations are given for several values of the exponent. These distribution concepts are applied to the experimentally obtained size distributions of droplets formed by the breakup of liquid woods metal (melting point 60°C.) dropped into a tank containing cold water. Conditions were chosen in such a manner as to attain hydraulic similarity. When the aerodynamic stagnation pressure exceeds the surface tension pressure, the drop is unstable and breakup occurs. Experimental setup is shown and described; breakup process and shape of resulting solidified drops are illustrated in high-speed photographs. Refers to HINZE 1949B, NUKIYAMA and TANASAWA 1940, and ROSIN and RAMMLER 1933B.

deJ II-111

C-31. Corcoran, J. W.

The Aerodynamic Breakup of Droplets. John W. Corcoran (George Washington Univ. Res. Lab., Washington, D.C.). Paper in ARMY CHEM. CENTER 1953, "Spray Dissemination of Agents", pp. 31–53, 16 fig.

Purpose was to determine the surviving fraction of an explosively disseminated bacteriological aerosol. Develops expression based on an initial Rosin-Rammler distribution. Experimental checking is difficult owing to evaporation, coalescence, and spreading. Therefore a substitute experiment was used, with a drop of Wood's metal of known weight being held at the top of a hot water tank, released, allowed to fall and break up in hot water, then chilled in cold water on the bottom of the tank. Experimental setup is illustrated and described, and the breakup of Wood's metal drop into smaller droplets shown in successive high-speed moving picture frames. Shows the final, solidified drops of various shapes. Charts of drop-size distribution are shown and compared with Beta functions having various parameters.

deJ II-111

C-32. Cosby, W. T.

"The Formation and Stability of Aerial Disperse Systems." W. T. Cosby. Bull. Brit. Coal Utilisation Research Assoc. 14, 201-11 (1950).

CA 45-32191

C-33. Courshee, R. J.

Testing a Spray Deposit Analyser. R. J. Courshee. Tech. Mem. No. 100, Natl. Inst. Agr. Engng., (Wrest Park, Silsoe, Bedfordsh.), 9 p., 15 fig., 3 tabl., 2 ref.

Pattern of spray droplets, deposited on the crop surface for disease and pest control, is an important factor of their biological effectiveness. Spray pattern can be analysed by microscope visually, or by a sizing and counting machine. This latter has been built on the principle of scanning the spray pattern with a scanning spot, as an adaptation of the Muirhead picture telegraph transmitter. This measures: (1) the dose per unit area of the active material, (2) the fraction of the area covered with spray, (3) frequency distributions of sizes of spray stains and of bare intervals between spray stains. Discusses: the scanner; the analyser; errors; signal generation and duration of signals formed by scanning lines of known widths; signal recording, and determination of accuracy in recording signals of known duration; spray pattern measurement; errors of machine measurement; errors of analysis.

deJ II-112

C-34. Courshee, R. J., and J. B. Byass

"A Study of the Methods of Measuring Small Spray Drops," Nat. Inst. of Agri. Engr. Report No. 31, 3 pp. Sept. 1953.

C-35. Crane, L., S. Birch and P. D. McCormack

21084 THE EFFECT OF MECHANICAL VIBRATION ON THE BREAK-UP OF A CYLINDRICAL WATER JET IN AIR.
L. Crane, S. Birch and P. D. McCormack.
Brit. J. Appl. Phys., Vol. 15, No. 6, 743-50 (June 1964).

An account of experimental investigation into the effects of high-amplitude high-frequency mechanical vibration on the break-up characteristics of a liquid jet in air is given. The main phenomenon of imposed periodicity of drop spacing and uniformity of drop size is described, along with several other interesting phenomena.

Graphical relationships between parameters such as vibration frequency, amplitude and break-up length are established. While the results largely confirm Rayleigh's original linear analysis with respect to the wavelength of maximum instability, considerable discrepancy is revealed in the magnitude of the amplification factor and considerable departure from linearity is indicated.

PA 67-21084

C-36. Crawford, A. E.

4462. Production of spray by high power magnetostriction transducers. A. E. Crawford. Letter in *J. Acoust. Soc. Amer.*, 27, *No.* 1, 176-7 (*Jan.*, 1955).

Produced by a window-type stack transducer in the frequency range 15 to 30 kc/s, the spray differs from the fog produced by higher frequency crystal transducers.

PA 58-4462

C-37. Crowe, C. T.; J. A. Nicholls, and R. B. Morrison

"Drag Coefficients of Inert and Burning Particles Accelerating in Gas Streams," Ninth Symp. (International) on Comb., Academic Press, New York, 1963 pp. 395-406.

C-38. Culp, G.

N64-33819 Air Force Inst. of Tech., Wright-Patterson AFB, Ohio School of Engineering
AN INVESTIGATION OF THE POSSIBILITY OF ELECTRICALLY ATOMIZING VOLATILE LIQUIDS
Gary Culp (M.S.Thesis) Aug. 1964 90 p refs
(GSP/Phys-64-1; AD-603682)

Liquids studied included distilled water, ionically doped water (H_2SO_4 in H_2O), and liquid nitrogen. The liquids were forced under pressure through small metal capillary tubes held at high positive potentials with respect to a nearby ground plate. Liquid nitrogen was studied at atmospheric pressure and in vacuo; water was investigated only in vacuo. Particles sprayed from the capillary tubes were monitored with charged particle detectors to measure any net electrical charge. Resulting sprayed particles in all cases had net charge insufficient to be detected above background noise. The lack of charge on the sprayed particles can be explained by analysis of the key times required for ion separation in the liquid versus the time the ions spend in the electric field (a study of liquid velocity versus ion mobility).

N64-33819, 24-11

C-39. Culverwell, J. F.

"Composition Change in Binary Component Spray Vaporization at Atmospheric Pressure." James F. Culverwell (Northwestern Univ., Evanston, Ill.). Univ. Microfilms (Ann Arbor, Mich.), Publ. No. 13,079, 93 pp. (microfilm, $1.16; paper enlargement, $9.30); Dissertation Abstr. 15, 1810 (1955).

C-40. Culverwell, J. F. et al

5239. Culverwell, J. F., Gouands, P. W., Jr., Lamb, G. G., and Stevens, W. F., Composition change in binary-component spray vaporization at atmospheric pressure, *AIChE J.* 2, 4, 555-560, Dec. 1956.

Author investigates factors affecting change of composition with vaporization of a binary component spray in heated air at atmospheric pressure. System orthodichlorobenzene-tetrachloroethylene was studied in air ranging from 400 to 1000 F, with drop diameters in the 20 to 400-micron range. Experiments indicated that rate of change of spray composition during vaporization was affected only by chamber-air temperature, the initial composition, and the nozzle characteristics. Mathematical expressions for the vaporization process are presented, liquid diffusion being assumed within the drop controls; these equations have been solved by stepwise procedures for three initial drop sizes. Statistical calculations are used to predict the vaporization behavior of the spray. The calculations agreed with previously obtained experimental data for the initial portion of spray travel from nozzle to tray; for subsequent portion of spray considerable deviation was found. Further experiments are needed to determine more precise values for drop-size distribution, initial drop velocity, and liquid diffusion coefficient. Experimental equipment and technique are described in detail, data of an experiment are tabulated, and sample calculations are carried out.

AMR 11-5239

D-1. Dalla Valle, J. M.

Micromeritics. The Technology of Fine Particles. J. M. Dalla Valle (Georgia Inst. Techn. Atlanta, Ga.) Pitman, New York, 2nd. Ed., 1947. 555 p., 126 fig. Bibliography of about 600 titles.

An exhaustive treatise on small solid particles, their measurement, dynamics, shape and size distribution; theory of sieving, characteristics of packings, behavior of particles under pressure, electrical, optical and sonic properties, thermodynamics, surface properties, chemical properties, flow of fluids through packings, capillarity, determination of particle surface, muds and slurries, transportation of particles, dust clouds, atmospheric and industrial dust, collection of particulate matter from air, theory of fine grinding, sampling. Sprays are treated only incidentally, but several chapters have a close applicability to sprays, in particular those dealing with dynamics of small particles, shape and size distribution, methods of particle size measurement, sieving, capillarity, and collection and separation of particulate matter from air.

deJ I-63

D-2. Darmois, G.

"Cathodic Atomizing of Electrolytic Solutions and Metals." Geneviève Darmois (Lab. Phys.-Enseignement, Paris). Compt. rend. 79° congr. soc. Savantes Paris et dépts., Sect. sci., Alger 1954, 17-20.

CA 51-11128

D-3. Darnell, W. H.

"Atomization by Centrifugal Pressure Nozzles," Ph.D Thesis, University of Wisconsin. 1953.

D-4. Dautrebande, L.

Studies on Aerosols. Lucien Dautrebande (Min. of Education, Brussels, Belgium). U.S. Atomic Energy Comm., Res. & Dev. Rep. UR-530; Univ. of Rochester Atomic En. Proj., Contr. No. W-7401-eng-49; Oct. 1, 1958, XI + 590 p., 94 fig., 13 tabl., about 3400 ref. with titles and bibliographic data.

Summarizes published and unpublished experimental and technical data on liquid and solid aerosols (inert, pharmacological, or toxic). Emphasizes production, measurement, and biological importance of submicronic and submicroscopic particles, and physiological and pathological effects caused by their retention in the respiratory tract. Chapters: production of liquid, micromicellar aerosols; production of solid, small-sized aerosols; pulmonary penetration of aerosols; importance of particle size for therapeutical aerosol efficiency; deposition rate of air-borne particles in the respiratory tract; practical recommendations for administering pharmacological aerosols; pharmacological and therapeutic application of liquid aerosols; applications of aerosols in hygiene (air sterilization, insecticide and fungicide uses, dust control, and dust agglutination).

deJ II-121

D-5. Dautrebande, L.

"Apparatus for Generation of Aerosols." Lucien Dautrebande. Ger. 1,027,189, Apr. 3, 1958

CA 54-12428c

D-6. Davies, C. N.

"Recent Advances in Aerosol Research," Pergamon Press, London, 1964, Dist. by Macmillan, New York, 80 p.

D-7. Davies, D. A., R. Venn, and J. B. Willis

"An Adjustable Atomizer for Atomic Absorption Spectroscopy," J. Sci. Instr. 42, 816-817 (1965)

D-8. Davis, J. M.

"A Vibratory Apparatus for Producing Drops of Uniform Size," USDA Bur. Ent. and Plant Quar., ET-295, 3 pp., 1951

D-9. "A Photographic Method for Recording Size of Spray Drops," USDA Bur. Ent. and Plant Quar., ET-272, 1949

D-10. Debeauvais, F.

4294. Debeauvais, F., Some aspects of disintegration of liquid jets in moving air: study of forced pulverization in an experimental carburetor (in French), 9th Congrès intern. Mécan. appl., Univ. Bruxelles, 1957; 2, 349-358.

Based on previous researches, mainly on Littaye (1942), atomization of liquid in a parallel stream of air is studied experimentally from the issuance of the jet from the nozzle until its complete disintegration into discrete drops of approximately spherical shape. A small wind tunnel of 8 cm × 8-cm cross section is used, with a glass nozzle of 1-mm diam. Air velocity was varied from 0 to 100 mps; liquid discharge was varied up to 0.5 cm^3/sec, giving a very lean mixture of air/liquid of the order of one million.

Velocity distribution in the cross section was found to be very even; velocity change and pressure change along the axis of the tunnel have been determined and charted. Three methods of observation were used: (1) a "semi-stroboscopic" visual observation (because the phenomenon is not periodic) for getting a general idea; (2) instantaneous photography using a flash of about 0.5 microsec duration, capable of separating drops of 5 micron diam; (3) ultra-rapid movie camera using double-flash illumination. Distilled water was used for liquid. The jet first forms a filament, which is spread out into a sheet, which in turn breaks up into droplets. Photographs illustrating these successive stages are shown.

AMR 11-4294

D-11. Debeauvais, F.

4293. Debeauvais, F., Some aspects of disintegration of liquid jets in moving air: study of forced pulverization in an aerograph (in French), 9th Congrès intern. Mécan. appl., Univ. Bruxelles, 1957; 2, 359-366.

Continuation of former research, by using an air-liquid ratio of less than 3000, using a compressor-type aerosol generator termed an "aerograph." The velocity distribution was measured with a miniature pitot tube, with and without water jet, and only little difference was found, but the velocity distribution itself was not even within the cross section. Instantaneous photographs are shown. Conclusions: At air-liquid ratios higher than 5000 (e.g., in carburetors) the effect of surface tension is predominant and the effect of viscosity is low; the formula of Nukiyama and Tanasawa was found to be valid. At air-liquid ratios below 5000 (as in the aerograph) the viscosity has great influence on the phenomenon of disintegration.

AMR 11-4293

D-12. Debye, P., and J. Daen

10658. STABILITY CONSIDERATIONS ON NONVISCOUS JETS EXHIBITING SURFACE OR BODY TENSION. P.Debye and J.Daen. Phys. of Fluids, Vol. 2, No. 4, 416-21 (July-Aug., 1959).

The question of the range of ejected liquid streams is connected with the relation of the stability of the jet motion to an initial infinitesimal disturbance. This is investigated as a theoretical problem for the planar and cylindrical cases neglecting any fluid viscosity. In addition, the stabilizing influence of either a surface or "body tension" is calculated. Comparison of the theory with some published data is found to yield qualitative and semiquantitative agreement. The possibility of applying this theory to the measurement of dynamic surface tensions is suggested.

PA 62-10658

D-13. DeCorso, S.M.

"Effect of Ambient and Fuel Pressure on Spray Drop Size" J. Eng. Power, 82, 10-18 (1960).

After a brief review of existing knowledge concerning the effect of ambient pressure on spray drop size, results are presented for a swirl nozzle at fuel Δp's of 25 and 100 psi for ambient gas pressures of 0.5, 14.5, and 114.5 psia. The liquid sprayed is diesel fuel, the nozzle capacity being 45 gal/hr at 100 psi Δp, and the nominal spray angle, 80 deg. The photographic method by which drop size was determined is described. Curves are presented which show the spatial variation in fuel flow rate, spray-stream velocity, and drop size. The notable effects are large drop size and velocity variations across the spray stream, and for the total nozzle output, an increase in the drop size as the ambient pressure goes from 14.5 to 114.5 psia. Some ramifications of the results are discussed.

Author

D-14. DeCorso, S. M.

"Effect of Ambient and Fuel Pressure on Spray Drop Size, ASME Gas Turb. Power Conf." Cincinnati, Ohio, Mar. 1959. Pap. 59-GTP-3, 9 pp.

D-15. DeCorso, S. M., and G. A. Kemeny

3356. DeCorso, S. M., and Kemeny, G. A., Effect of ambient and fuel pressure on nozzle spray angle, ASME Gas Turbine Power Div. Conf., Washington, Apr. 1956. Pap. 56-GTP-3, 7 pp. + 16 figs.

Samples taken diametrically across the fuel spray at a distance of 4-1/2 in. from the nozzle tip were obtained for ten centrifugal-type nozzles of 9 to 100 gallons-per-hour capacity, having nominal spray angles of 45 and 80 deg. Data were taken over a fuel-pressure range of 25 to 400 psi and for ambient pressures from 0.1 to 8 atm. These diametral spray distributions were reduced to equivalent spray-angle values which, when plotted against ambient and fuel pressure, provided a summary of the pressure effects on the spray angle. The spray angle decreased markedly with increasing fuel and ambient pressure; explanation for this is given. The equivalent spray angle was found to be a function of the product of fuel pressure drop and ambient gas density to the 1.6 power.

Survey is included of previous NACA research on centrifugal nozzles. Authors describe the very complete test equipment, details of operation, possible errors and their mitigation. Possible effect of combustor chamber walls, and of flow of combustion air, on the spray form and characteristics is estimated.

AMR 10-3356

D-16. Defay, R., and J. Hommelen

Bibliographie critique sur les methodes de mesure des tensions superficielles dynamiques (Bibliography, with critical comments, on measuring methods for dynamic surface tension). R. Defay and J. Hommelen. Industrie Chimique Belge, Vol. 23, No. 6, 1958, pp. 597–614, 233 ref. (no titl.).

Lists the various methods used for measurement of dynamic surface tension, subdivided in the following system: I. Measurements on flowing liquid (suitable for very short duration of surface): a) the bell; b) flowing sheet; c) vertical jet impinging on an obstacle; d) oscillating jet; e) simple jet; f) overflowing funnel; g) channel. II. Measurements on motionless surfaces: a) sessile bubble; b) pendent drop; c) falling drop; d) maximum bubble pressure; e) capillary rise; f) falling meniscus; g) ring; h) dipping plate; i) surface balance. For each of these methods references are given, and their characteristics, advantages and disadvantages, and fields of applicability are briefly discussed.

deJ II-125

D-17. Degtev, O. N.

2693. Degtev, O. N., Atomization of viscous liquids (in Russian), *Tr. Ural'skogo Politekhn. In-ta* no. 61, 95-105, 1956; *Ref. Zh. Mekh.* no. 9, 1957, Rev. 10263.

Existing presentations of the process of atomization of liquids are discussed. An analysis is carried out of the formulas proposed by different authors for the calculation of the diameter of the drops of liquid in the process of atomizing. On the basis of known facts regarding the atomizing process a deduction is made on the existence of two variants of this process: (1) the break-down of the stream under the influence of static instability; (2) the secondary fractionation of the drops when the determining factor appeared to be the effect of aerodynamical forces. Author regards as inconsistent the attempts to obtain a relation between the final diameter of the droplets and the original parameters by the aid of the theory of instability of the jet and the theory based on the reaction of turbulence on the break-down of the jet. Criteria are deduced, characterizing the atomizing process, by investigations of the forces acting on the droplets during secondary fractionation (aerodynamic forces, forces of internal friction and forces of surface tension). The criterial equation for the atomizing process of a viscous liquid has the form

$$D = A\Pi^n, \; D = \frac{\rho w^2 d}{\sigma}, \; \Pi = \frac{\mu w}{\sigma}$$

where D is the fractionation criterion, ρ the density of the surrounding medium, μ the viscosity of the liquid being atomized, σ the surface tension coefficient, w the relative velocity of the droplet, d the diameter of the droplet. Experiments were carried out on the atomizing of slag obtained from the cupola-furnace smelting (of iron ore) (composition: silicon oxide ~ 43%, calcium oxide 24%

aluminum oxide ~ 17%, the remainder—oxides of iron and magnesium). For the atomizing a pneumatic sprayer was used and a device with rotating vanes. The slag particles after atomizing were air cooled and then sieved in order to obtain the curves for classification by particle size. The experiments showed that when atomizing slag with the aid of rotating vanes for a range of criteria $\Pi < 40 < 1700$ the coefficients of the criterial equation have the values of $A = 1.72$, $n = 0.425$.

AMR 12-2693

D-18. Degtev, O. N.

5305. Degtev, O. N., Deformation of drops in a flow of gas and the drops' stability limit (in Russian), *Trudi Ural'skogo Politekhn. In-ta*, no. 61, 106–112, 1956; *Ref. Zh. Mekh.* no. 4, 1958, Rev. 4080.

Paper is devoted to the investigation of the deformation and atomization of drops in a gas flow. Based on this the author is of the opinion that it is possible to differentiate the characteristic regimes in the flow of liquid jets (the presence or absence of secondary breakdown of drops after disintegration). It is assumed that the drop (when conditioned by a noticeable influence of the forces of surface tension) can be deformed either into a disk, or a cylinder with rounded ends. Computing the mean surface value of normal pressure on the sphere and levelling up its surface tension pressure, author obtains a value for the magnitude of the criterion of breakdown for the beginning of the deformation

$$D = \frac{\rho w^2 d}{\sigma} = 9.2 \qquad (1)$$

where w, d are the relative velocity and diameter of the drop, respectively, ρ the gas density, σ the coefficient of surface tension. Application of the analogous argument to the liquid cylinder (the relation of its length to the diameter is assumed to be 4) gives the critical value

$$D_* = \frac{\rho w_*^2 d}{\sigma} = 16.1$$

Here w_* is the critical value of the relative velocity of the drop. Author proceeds to compare the figures obtained with the corresponding experimental values found by the abstractor and reports good agreement. The method employed by the author appears to be roughly approximate and is likely to yield only a conception of the order of values of the breakdown criterion.

AMR 12-5305

D-19. DeJuhasz, K. J., et al.

Book—1515. DeJuhasz, K. J., Selechitano, E. A., et al, Spray literature abstracts, New York, American Society of Mechanical Engineers, 1959, viii + 383 pp.

Compilation lists over 1300 articles, papers, books, reports, and other literature items dealing with the scientific, technical and industrial aspects of sprays, as well as associated phenomena and disciplines. The items have been collected from about twenty-four countries and cover the period from about 1880 up to March 1959. The entries cover: the mathematics, physics and chemistry of sprays; the hydro-, aero-, thermodynamics and rheology of sprays; the break-up of liquid stream into drops, and their motion in air, their evaporation and combustion; optical and electronic devices for the experimental study of sprays; branches of mechanical and production engineering entering into the design, production, and testing of pumps, nozzles and other elements of spray generating equipment; borderline and associated disciplines, such as the science and technology of powders and dusts.

The following fields of application are covered: fuel sprays for furnaces, internal combustion engines, gas turbines and rockets; sprays in industrial processes for evaporation drying, humidification, cooling, air-conditioning, and chemical reactions; atmospheric sprays, such as rain, fog, haze, sleet and snow, their formation, evaporation and freezing; agricultural sprays for sprinkling, pest, fungus, and weed control: fire-fighting sprays, as in sprinkler systems and in fire-smothering fogs; aerosols for medical disinfecting, therapeutic, and air-conditioning purposes; sprays and fogs for military purposes in defense and attack. The entries contain full bibliographic data, and in most cases also give concise and detailed abstracts. The affiliation and address of the authors is given in most cases. The book is intended to be a source book on the subject, to aid research workers in their search for previous work related to their problems, to help avoid duplications of effort, and to contact other workers active in related fields.

AMR 13-1515

D-20. DeJuhasz, K. J., O. F. Zahn, and P. H. Schweitzer

On the Formation and Dispersion of Oil Sprays. K. J. DeJuhasz, O. F. Zahn, and P. H. Schweitzer. Penna. State Coll., Eng. Exp. Sta. Bull. No. 40 (1932), 93 p., 56 fig., 54 ref.

Report on experiments to determine dispersion characteristics of spray as used in fuel injection engines. Various liquids used; factors determining break-up distance. Drops caught in nonmiscible medium; drop sizes determined by photo micrography. Volumetric distribution of sprays determined with "dispersion rack", holding blotting paper pads intercepting the spray at various locations, which were weighed before and after injection. Determination of "flux lines" of sprays; interpolation made on the basis of probability theory. Explanation of drop formation. Conclusions regarding engine design and operation.

deJ I-69

D-21. Delavan

Spray Droplet Technology. Engrg. Dep., Delavan Mfg. Co. (West Des Moines, Iowa). Publ. Delavan Mfg. Co. 1958, 16 p., 12 fig., 3 ref.

Describes the firm's spray laboratory facilities and explains some basic concepts of sprays, droplets, their characteristics and representations. The "Spray Droplet Analyser" simplifies the task of determining the droplet-size distribution, using a scanning technique to count and classify droplet images on photographic negatives. The negatives are obtained by photographing spray samples collected in the droplet spray sampler. The images of droplets are scanned by a photocell and are electronically sorted into 30 size classes. The equipment is illustrated by schematics and photographs and their operation explained. Plotting of the size distribution curve is explained; various "mean" diameters are defined; a numerical example is given.

deJ I-70

D-22. Dempster, J. R. H., and M. S. Sodha

"On Secondary Atomization of Droplets," Jet Propulsion 27, 8 (part 1), p. 896, Aug. 1957.

D-23. de Ong, E. R., K. C. Peer, and L. W. Fancher

"New Generator for Producing Dry Aerosols with Organic Insecticides. E. R. de Ong, Kenneth C. Peer, and L. W. Fancher. J. Econ. Entomol. 43, 542-6 (1950).

D-24. Deryagin, B., and G. Vlasenko

Deryagin, B. and Vlasenko, G.
THE FLOW METHOD OF ULTRAMICROSCOPE MEASUREMENT OF THE PARTICLE CONCENTRATION OF AEROSOLS AND OTHER DISPERSION SYSTEMS. [1959] 6p. (2 figs. omitted) 2 refs.
Order from LC or SLA mi$1.80, ph$1.80 59-17171

Trans. of [Akademiya Nauk SSSR. Doklady] 1948, v. 63, no. 2, p. 155-158.

A method is suggested for making a particle count in a continuous stream of aerosol flowing in a direction parallel to the line of sight, with the particles traversing a zone of illumination in a set time. If the total observed number of the little flashes in the field of view made by particles crossing the zone of illumination is divided by the volume of the aerosol flowing over the field, the particle concentration is obtained.

T2-485

D-25. Diamant, W.

5618. Diamant, W., Photomicrographic study of the atomization of combustible liquids in the interior of a combustion chamber (in French), *Chaleur et Industrie* 42, 436, 325-350, Nov. 1961.

A rotating plane mirror permits improved local photography of sprays of kerosene and domestic fuel oil. The experimental technique is described in good detail. A semiempirical outline of the present level of understanding of atomization is incomplete.

AMR 15-5618

D-26. Dickerson, R. A., and M. D. Schuman

A65-16959 #
RATE OF AERODYNAMIC ATOMIZATION OF DROPLETS.
Robert A. Dickerson and Merlin D. Schuman (North American Aviation, Inc., Rocketdyne Div., Canoga Park, Calif.).
(American Institute of Aeronautics and Astronautics, Heterogeneous Combustion Conference, Palm Beach, Fla., Dec. 11-13, 1963, Preprint 63-498.)
Journal of Spacecraft and Rockets, vol. 2, Jan.-Feb. 1965, p. 99, 100.
Contract No. AF 49(638)-817.

Presentation of quantitative expressions for the mass rate of atomization from droplets and plane liquid surfaces which are subjected to high relative gas velocities. The theoretical derivation for the plane surface rate expression is based on the existence of capillary waves which are generated on the surface of the liquid. The geometrical problems associated with the atomization from a droplet necessitate the use of an empirical relationship. The necessary constant for the atomization of droplets is evaluated. The constant for atomization from plane surfaces is not evaluated, but a general order of magnitude is predicted.

A65-16959, 07-09

D-27. Dimmick, R. L.

"Jet Disperser for Compacted Powders in the 1-10μ Range," AMA Arch. Ind. Health 20, 8-14 (July 1959)

D-28. Dimmick, R. L., M. T. Hatch, and J. Ng

13505* A Particle-Sizing Method for Aerosols and Fine Powders. Robert L. Dimmick, Melvin T. Hatch, and James Ng. *Archives of Industrial Health*, v. 18, no. 1, July 1958, p. 23-29.
Technique to estimate the particle size distribution of an aerosol without disturbing its characteristics is applicable to any chamber wherein aerosols undergo stirred settling. This procedure, termed the light scatter decay (LSD) method, involves a simplified analysis of the change in light intensity of a Tyndall beam as an aerosol settles under turbulent conditions.

BMI 7-13505

D-29. Dimmock, N. A.

The Controlled Production of Streams of Streams of Identical Droplets. N. A. Dimmock. National Gas Turbine Establishment (Engl.). Memo. M. 115, 1951, 13 p., 5 fig., 2 ref.

By means of a flexible capillary tube, excited to its natural period of vibration by means of an electro-magnet fed by a 50-cycle a.c. current, drops of uniform size are generated and thrown off, evenly spaced, always in the same phase of vibration. The drop diameter can be varied within the range 10 to 300 microns by adjusting the liquid feed. Because the drops are uniform and their generation occurs always in the same phase of the vibration cycle, therefore their formation can be observed in slow motion in stroboscopic light and photographs obtained at any phase of formation. A possible modification of the apparatus is in which the end of the capillary tube moves on a circular or elliptical path. Another modification is suggested but not tried, by using a hollow-shaft motor fitted with capillary tubes about the circumference, rotating about a vertical axis. (See: DIMMOCK 1960.)

deJ I-73

D-30. Dimmock, N. A.

875. Production of uniform droplets. N. A. Dimmock. Letter in *Nature, Lond.*, 166, 686-7 (*Oct.* 21, 1950).
A method is described whereby streams of droplets of uniform size may be generated by the vibration of a hollow glass reed containing the liquid. The vibrations in the reed are induced by means of a short length of steel hypodermic tubing, attached to the reed and acting as an armature, which itself oscillates under the influence of a small electromagnet supplied with a.c. By adjustment it is possible to obtain diameters ranging from 10 to 300μ.

PA 54-875

D-31. Dityakin, I. F.

795. Dityakin, Y. F., On stability and disintegration into drops of a liquid jet of elliptic section (in Russian), *Izv. Akad. Nauk SSSR. Otd. tekh. Nauk* no. 10, 124-130, 1954.

The jet, of ideal liquid surrounded by fluid, is disturbed in such a way that the surface varies periodically with time and with distance from the orifice. Author uses elliptic coordinates and Mathieu functions to find the critical frequency at which the jet becomes unstable. A dimensionless graph of frequency against pitch shows that the more nearly circular the section, the finer the drops.

AMR 9-795

D-32. Dityakin, I. F., and L. N. Britneva

Ditiakin, U. F., and Britneva, L. N., Generalization of measurement results of drop sizes of the liquids pulverized by centrifugal atomizer with the assistance of dimensionless criteria (in Russian), *Teploenergetika* no. 11, 33-36, Nov. 1959.

D-33. Dityakin, I. F., and V. I. Iagodkin

Dityakin, I. F. and Yagodkin, V. I.
EFFECT OF PERIODIC OSCILLATIONS OF VELOCITY AND DENSITY OF A MEDIUM ON DISINTEGRATION OF LIQUID JETS (Vliyaniye Periodicheskikh Kolebanii Skorosti i Plotnosti Sredy na Raspad Zhidkikh Struy) tr. by S. Reiss. Apr 61, 11p. 7 refs. NASA Technical trans. F-63; AD-253 469.
Order from OTS $0.50 61-21952

Trans. of Akad[emiya] Nauk SSSR. Otdel[eniye] Tekh[nicheskikh] Nauk. [Izvestiya] 1957, no. 4, p. 115-120.

The influence of the oscillations of the velocity in a liquid jet and the density of the medium surrounding a cylindrical jet, on the disintegration of the jet, is considered theoretically. The method of small perturbations beginning with the velocity potential equation is used. The following conclusions were derived: (a) during the oscillations of the velocity of a liquid jet the character and the length of the waves of the unstable perturbations are subject to change and there appears a great number of separate unstable oscillations, (b) the oscillations of the velocity of the liquid jet and the density of the surrounding medium cause a decrease in the dimensions of the drops appearing during the process of disintegration, and (c) the theoretical results are in agreement with experimental tests. (NASA abstract)

T5-685

D-34. Dobbins, R. A., et al.

2504. Dobbins, R. A., Crocco, L., and Glassman, I., Measurement of mean particle sizes of sprays from diffractively scattered light, *AIAA J.* 1, 8, 1882-1886, Aug. 1963.

The angular distribution of scattering for polydispersions of particles distributed according to the upper limit distribution function is examined and is found to lack the sensitivity necessary to permit determination of size distribution. However, the volume-to-surface mean diameter is found to be directly dependent upon angular distribution of intensity for a wide variety of shapes of the distribution function. Therefore, the combination of both a scattering experiment together with a transmission experiment can be used to obtain both particle concentration and volume-to-surface mean diameter of particles in a spray. While there is no limitation with regard to the maximum diameter, the actual upper size limit that is measurable e[illegible]entally is controlled by considerations related to angular resolving power. Experimental results that show agreement between the volume-to-surface mean diameter as determined by scattering experiment and by microscopic examination are given for solid spheres.

AMR 18-2504

D-35. Doble, S. M.

Design of Centrifugal Spray Nozzles for Outputs up to 1800 gallons per hour. S. M. Doble. Proc. Inst. Mech. Eng. (Engl.), Vol. 157 (1947), pp. 103–111, 8 fig., 1 ref.

Extends author's previous work (DOBLE 1945) to larger nozzles with spray cone angles up to 150°. Deals with the design and calibration results of such nozzles, also some drop size measurements by previously reported method. Nomogram for determining the design dimensions of nozzles for given flow rate, pressure, and cone angle. Discussion by several research workers on pp. 116–119.

deJ I-74

D-36. Doble, S. M.

Design of Spray Nozzles. S. M. Doble. Engng. (Engl.). Vol. 159 (1945), pp. 21–23, 61–63, and 103–104, 23 fig., Abstract in: Eng. Dig., Vol. 2 (1945), pp. 298–303, 12 fig.

Report on centrifugal nozzles. Discharge was measured as a function of the variation of various nozzle dimensions. Drop size determination by collection in a subdivided shallow pool of castor oil above a layer of vaseline. Photomicrographs at 41-times magnification were taken on photographic paper. A second method, particularly for very small drops, was to use a high resolution photographic plate covered with a thin film of a mixture of equal parts of paraffin and hydraulic oils. The sprayed plate was then exposed to parallel light, thus photographing the drops. Microscopic inspection or rephotographing was used for counting. Influence of evaporation on the accuracy of the drop size measurements was studied in detail. Nomograms are given for determining the design dimensions of nozzles for given flow rate, pressure, and spray cone angle.

deJ I-74

D-37. Doble, S. M., and E. M. Halton

The Application of Cyclone Theories to Centrifugal Spray Nozzles. S. M. Doble and E. M. Halton. Proc. Inst. Mech. Eng. (Engl.), Vol. 157 (1947), pp. 111–116, 5 fig. (Discussion by O. N. Lawrence, pp. 117–119).

Suggest that in nozzle design the ratios: spinning speed at inlet radius to inlet velocity, and mean inlet radius to exit radius, be chosen greater than 1. Such values permit accurate prediction of design data but they may have to be modified in the final design to obtain the desired spray characteristics. Give formulas defining the design dimensions of nozzles; give some experiments in support of their theories. Discussion by several research workers.

deJ I-74

D-38. Dodd, K. N.

On the Disintegration of Water Drops by Shock Waves. K. N. Dodd. Roy. Aircraft Establ. (Farnborough, Engl.). Tech. Note M S. 64 (Min. of Aviation, London W.C. 2), May 1960, 11 p., 3 fig., 6 equ., 4 ref.

In absence of aerodynamic forces, a drop of water will assume a spherical shape under influence of surface tension. With gradually increasing velocity between the drop and air, the drop will be distorted. For a suddenly applied relative motion, such as occurs near explosions, the outer surface is stripped off while the central portion remains relatively at rest (ENGEL 1958). Theoretical aspects are investigated based on established properties of fluids; it is not possible to present a precise mathematical treatment, only a mechanism giving a qualitative explanation, especially for the time required for disintegration. Refers to JENKINS 1957 and SAVIC 1953.

deJ II-135

D-39. Dodd, K. N.

On the Disintegration of Water Drops in an Air Stream. K. N. Dodd (Royal Aircraft Establ., Farnborough, Engl.). Jl. Fluid Mech. (Cambridge Univ. Press, London), Vol. 9, Part 2, Oct. 1960, pp. 175–182, 2 fig., 5 ref.

Based on available experimental evidence a theory is developed to predict distortion and disintegration of a water drop when it is exposed to an air stream with continuously increasing relative velocity. ..., and also illustrates, the following stages: as the relative velocity is increased ... the initially spherical drop has its leading surface flattened, then the flattened surface becomes concave; the hollow increases in depth until it almost protrudes through the back of the drop; then a spherical, bag-shaped bubble begins to develop, the bubble expands rapidly from the annular ring of water on which it is formed; the sheet of water forming the bubble eventually becomes unstable and breaks up into droplets; soon after this also the annular ring becomes unstable and breaks up into larger drops. Develops equations for values of the relative velocity at which these steps occur. Refers to HINZE 1949A and 1949B; FAGE 1937; PRANDTL 1952.

deJ II-135

D-40. Dodd, K. N.

"On the Disintegration of Water Drops in an Air Stream," RAE Tech. Note No. M.S. 61, NASA N 82663, 1960.

D-41. Dodge, L. A., W. W. Hagerty, and J. L. York

Continuous Fuel Sprays. R. A. Dodge, W. W. Hagerty and J. L. York (U. of Michigan). A. F. Techn. Rept. No. 6067, Contract No. W 33–038–ac–21230, U. of Mich., Power Plant Lab., Eng. Div., 1950. 71 p., 22 fig., 106 ref.

The problem of fuel spray analysis and the specific items of study undertaken are discussed. Literature is reviewed, and published theories, experimental results, and techniques are evaluated. A photographic method is described for providing more rapid calibrating for analyzing sprays. This consists of a low-magnification camera and lens, with a light flash of high intensity and short duration, providing illumination and controlling the exposure. The small fraction of the spray under study is in a shallow focal region of the camera. A mechanical-electrical device for accurately and quickly determining spray patternation and flow characteristics is described. This consists of a cantilever bar fitted with a strain gage. An RCA 5734 mechano-electronic transducer was also tried. Examples are presented of the type of information obtained by both the photographic method and the rapid analyzing devices.

deJ I-75

D-42. Dodu, J.

A65-17562
CONTRIBUTION TO THE STUDY OF THE DISPERSION OF HIGH-SPEED LIQUID JETS [CONTRIBUTION A L'ETUDE DE LA DISPERSION DES JETS LIQUIDES A GRANDE VITESSE].
J. Dodu (Grenoble, Université, Faculté des Sciences, Grenoble, France).
France, Ministère de l'Air, Publications Scientifiques et Techniques, no. 407, July 1964. 94 p. 24 refs. In French.

Presentation of a definition of the dispersion of high-speed liquid jets penetrating into still air (a phenomenon of aleatory character and of relatively small amplitude), with attachment to the dispersion of a numerical value which can be checked by experiment in a tangible and accurate way. The numerical value is calculated by starting from statistical samples of high-speed photographs. The study of the influence of fluid properties (viscosity, surface tension) on the dispersion shows, for fast, slightly dispersed jets, that surface tension has a strong effect.

A65-17562, 07-09

D-43. Dodu, J.

13056. THE INFLUENCE OF THE WEBER AND REYNOLDS NUMBERS ON THE DISPERSION OF HIGH-SPEED LIQUID JETS.
J. Dodu.
C.R. Acad. Sci. (Paris), Vol. 249, No. 4,499-501 (July 27, 1959). In French.

The dispersion or increase in diameter of a high-speed liquid jet in air is shown experimentally to be linear. The dispersion angle depends more strongly on the Weber number than on the Reynolds number.

PA 62-13056

D-44. Dombrowski, N., et al.

1239. Dombrowski, N., Eisenklam, P., and Fraser, R. P., Flow and disintegration of thin sheets of visco-elastic fuels, *J. Inst. Fuel* **30, 198,** 399–406, July 1957.

Viscoelastic hydrocarbon gels have very high resistance to disintegration. The maintenance of flame along the jet of fuel depends upon the generation of a combustible mixture and, thus, on the rate of vapor release. This, in turn, depends upon the rate of development of new surface, which is controlled by the manner of disintegration of the fuel. Gels of very low, up to very high, consistency have been discharged through single-hole, fan-spray nozzles to form sheets, for comparison with the disintegration of normal liquids. Whereas normal liquids yield droplets at disintegration, the sheets of viscoelastic gels may disintegrate into threads and not drops. For normal liquids, ejected into an atmosphere of reduced density, the laminar sheet becomes placid and the mode of disintegration changes. With a sheet of gasoline, normally ignited, the ignition zone is in front of the zone of disintegration and the flame has no effect on the manner of disintegration. If, however, the sheet is surrounded by flame it becomes placid and the mode of disintegration changes because the local conditions are equivalent to sub-atmospheric density. This is important for the disintegration of fuel by pressure nozzles in combustion chambers. Nozzles and spraying apparatus are described and illustrated; photographic equipment described. Charts are given for pressure versus velocity, pressure loss in nozzle versus pressure, coefficient of discharge versus pressure, and versus consistency. Photographs show disintegration of sheets into filaments and into droplets, both as ignited and as not ignited.

AMR 11-1237

D-45. Dombrowski, N., and R. P. Fraser

9968. **A photographic investigation into the disintegration of liquid sheets.** N. DOMBROWSKI AND R. P. FRASER. *Phil. Trans A*, 247, *No.* 924, 13–130 (1954).

This paper gives further insight into the manner of disintegration of liquid sheets by the use of an improved photographic technique. It establishes the basic mechanisms of thread and drop formation and shows that the liquid threads are principally caused by perforations in the sheet. It shows that the history of the perforations determines the stage of growth at which the threads break up. If the holes are produced by air friction the threads so produced are broken up very rapidly by the air and they may be difficult to observe. If, however, the holes are caused by other means, such as turbulence in the nozzle or suspensions of unwettable particles, the threads are broken more slowly by surface tension. The life history of the holes appears to have an important bearing on the resultant drop size, and it would appear that if the perforations in the sheet could be made to occur at the same distance from the orifice, then the thread diameters and resulting drops could be made to be more uniform.

PA 57-9968

D-46. Dombrowski, N., R. P. Fraser, and G. T. Peck

5345. **A short duration, double-flash system for simultaneous or delayed operation.** N. DOMBROWSKI, R. P. FRASER and G. T. PECK. *J. sci. Instrum.*, 32, *No.* 9, 329–31 (*Sept.*, 1955).

An account is given of the development of an apparatus employing two separate flash discharge tubes operated either simultaneously or consecutively with a means to vary the interval from 0·01 to 10 msec. The two sources of an energy of 5 J are designed for a flash duration of 5 μsec at 10% of peak light. An example is given of the application of the apparatus to the study of the mechanics of spray nozzles.

PA 58-9345

D-47. Dombrowski, N., D. Hasson, and D. E. Ward

836. **Dombrowski, N., Hasson, D., and Ward, D. E., Some aspects of liquid flow through fan spray nozzles,** *Chem. Engng. Sci.* 12, 35–50, 1960.

Flow pattern of liquid sheet produced from a rectangular-orifice fan-spray nozzle was investigated, with emphasis on the manner in which its thickness varies from the orifice to the point of breakup. The trajectory of its boundary is analyzed on the assumption that the curvature of the edge of the sheet is due to surface tension. After surveying previous experimental methods for measuring the sheet thickness, the used apparatus, with double-reflection illumination, is described. Measurements of trajectory were made on the large clear photographs obtained. Main results are: (a) The streamlines of the spray sheet are straight and unaffected by the curved boundary. Velocity along the streamlines is constant, and independent of viscosity. (b) Sheet thickness at any point is inversely proportional to distance from the orifice, and can be expressed, for a given set of operating conditions, by a thickness parameter. (c) At low injection pressure the thickness parameter is a function of surface tension and of a factor composed of the injection pressure, density, and viscosity; at high injection pressure the thickness parameter is a function of the factor only (but not of the surface tension). (d) The trajectory of the sheet is a function of injection pressure, sheet thickness, and surface tension, and is independent of liquid density.

Advantage of method is that the entire sheet is depicted in one photograph, taken at 1/50-sec exposure, and its clarity permits an accurate evaluation. This is a highly informative paper, with clear exposition of the principles used, employing a well-conceived, simple, and effective experimental technique.

AMR 14-836

B-48. Dombrowski, N., and P. C. Hooper

7553. **Dombrowski, N., and Hooper, P. C., A study of the sprays formed by impinging jets in laminar and turbulent flow,** *J. Fluid Mech.* 18, 3, 392–400, Mar. 1964.

It is shown by high-speed still and moving pictures that disintegration of impinging liquid jets generally results from formation of unstable waves of aerodynamic or hydrodynamic origin. The results of this study indicate that the hydrodynamic (or impact) waves are generated when the Weber number of the jet is above a certain critical value, and that their formation is independent of jet Reynolds number. Drop sizes were measured and are shown to depend upon the mechanism of disintegration. The mechanism of disintegration depends on the jet velocity, angle of impact, and whether the jet is laminar or turbulent.

AMR 17-7553

D-49. Dombrowski, N., and P. C. Hooper

"The Performance Characteristics of an Impinging Jet Atomizer in Atmospheres of High Ambient Density," Fuel 41, 323-34 (1962).

A study has been made of the performance characteristics of an impinging jet atomizer injected in air atmospheres ranging in density from near vacuum to 0·025 g/cm³ (300 lb/in² gauge). It is found that the effect of air density on the processes of drop formation is dependent on the level of air density employed. Below atmospheric density liquid turbulence predominates in disintegrating the liquid sheet and the mean drop size is sensibly independent of density. As the density is increased above atmospheric, aerodynamic forces assist the atomization and the drops initially diminish in size. However, at an air density of approximately 0·01 g/cm³ the drop size attains a minimum value and thereafter air density causes the drops to increase in size. These results are explained in the light of earlier findings. Observations have also been made of the flight of the drops and data are given for their velocity and frequency under a wide range of operating conditions.

Author

D-50. Donnelly, J. J., and K. Wohl

"Progress on Spray Research," Chem. Engineering Project No. 62, Univ. of Delaware Report No. 106, Aug. 23, 1950. 18 pp., 25 fig.

D-51. Dorman, R. G.

3448. Dorman, R. G., **The atomization of liquid in a flat spray,** *Brit. J. appl. Phys.* 3, 6, 189-192, June 1952.

The investigation deals with the formation of flat sprays produced by agricultural nozzles with water, and kerosene, at differential pressures in the range of 45 to 105 psia. Spark photography was used in the study of spray development. Drop-size distribution was determined from patterns made on filter paper by dyes added to the sprayed liquid.

The Nukiyama-Tanasawa equation was used to determine the Sauter mean diameter. A new diameter, designated D_p, the value of the 99.99% number was introduced. This and the Sauter mean diameter were found to be related to the volume of liquid sprayed in unit time, spray angle, surface tension, liquid density, and pressure differential. Influence of viscosity was considered negligible. The two diameters may therefore be predicted.

It was concluded that the drops are formed according to the Castleman ligament theory. Extreme care was exercised to assure still air and high humidity during the tests. However, "the nozzle was carried smartly across the layout, spraying horizontally and pointing down the line." Reviewer believes that this procedure nullifies the use of the experimental data in the derived equations, since the pressure differential is no longer related to the velocity of the spray relative to still air.

AMR 5-3448

D-52. Doumas, M., and R. Laster

Liquid-Film Properties for Centrifugal Spray Nozzles. M. Doumas and R. Laster (General Foods Corp., Hoboken, N.J.). Chem. Engng. Progr., Vol. 49, No. 1?, Oct. 1953, pp. 518–526, 18 fig., 21 equ., 4 tabl., 7 ref. 2 app. with 22 equ.

Cited in NELSON and STEVENS 1961 and VALDENAZZI 1956. Refers to NOVIKOV 1948, and VÖRÖS 1935. Investigated correlation between physical dimensions of nozzle and the properties of the liquid sheet issuing from the nozzle. Presents expressions for coefficient of discharge, thickness of liquid film and its velocity components, size of air core, spray angle. Calculation is explained by a numerical example. Treats: review of literature and general considerations; experimental equipment and procedures (reaction-measuring balance, angle-measuring apparatus, photographic set up for measuring the air core); analysis of data and results. Most of experimental work was performed with "Whirljet" type nozzles of Spraying Systems Co. Appendix presents detailed derivation of equations of fluid flow in centrifugal nozzles.

deJ II-137

D-53. Doyle, W. W., B. V. Mokler, and R. R. Perron

"New Means of Fuel Atomization," API Conference on Distillate Fuel Combustion, Chicago, June 19-20, 1962. Paper No. CP 62-1.

D-54. Doyle, G. J. P.

"Sonic Determination of Particle Size in Aerosols." George J. P. Doyle (Indiana Univ., Bloomington). Univ. Microfilms (Ann Arbor, Mich.), Publ. No. 14651, 182 pp. (microfilm, $18.20); Dissertation Abstr. 16,248 (1956).

D-55. Drazin, P. G.

4455. Drazin, P. G., Stability of a broken-line jet in a parallel magnetic field, ***J. Math. Phys.*** **39, 1, 49–53, Apr. 1960.**

Author considers two incompressible inviscid electrically conducting fluids, namely a jet of uniform velocity surrounded by an infinite fluid at rest, with a uniform parallel magnetic field, and investigates the stability of the flow to small perturbations. The most interesting result is that at all finite magnetic Reynolds numbers the flow is unstable to long-wave disturbances. There appears to be a misprint on line 10 of page 53 where "stability" should read "instability".

AMR 14-4455

D-56. Drazin, P. G.

291. Drazin, P. G., Discontinuous velocity profiles for the Orr-Sommerfeld equation, ***J. Fluid Mech.*** **10, 4, 571–583; June 1961.**

Author shows mathematically that stability characteristics at small wave number of a half-jet and a jet of a viscous, incompressible fluid can be obtained by using basic flows with discontinuous velocity profiles for Orr-Sommerfeld equation. Method developed has limited use in unbounded flows only. Results are of mathematical interest.

AMR 15-291

D-57. Drozin, V. G.

7479. The electrical dispersion of liquids as aerosols. V. G. Drozin. ***J. Colloid Sci.,*** **10, *No.* 2, 158–64 (*April,* 1955).**

The dispersibility of a series of liquids at high electric potentials was investigated experimentally and theoretically. Large electrostatic pressure plays a predominant part in the process of dispersion and is a function of dielectric constant and radius of curvature of the liquid in the capillary. Nonpolar organic liquids having small dielectric constants could not be dispersed. Prediction of the dispersibility of a liquid can be made from knowledge of the value of its dielectric constant.

PA 58-7479

D-58. Druett, H. A., and K. R. May

Production of Individual Sized Droplets by High-Voltage "Firing" from a Micropipette. H. A. Druett and K. R. May (Microbiological Res. Dep., Min. of Supply, Porton, Wilts. Engl.). Nature, Vol. 174, Sept. 4, 1954, pp. 467–469, 2 ref.

Uniform size droplets can be produced: in the range below 10 microns with the LaMer vapor condensation apparatus, between 10 to 1000 micron by the spinning disc principle, 100 micron to several mm. by the vibrating tip, interrupted jet, and microburette principles, and 800 micron to 6 or 7 mm. by liquid falling by gravity from the tip of a vertical tube. Only the last method is suitable to produce individual drops, but only large ones. Developed method for producing individual drops, down to 10 micron size, by using a micropipette and applying a momentary high-voltage to the liquid. The technique, required pipette sizes, how to make them, and required voltages for each size pipette, are given in detail. Used the droplets for experiments on the evaporation rates of various airborne droplets, but suggest also other uses, such as combustion studies, application of insecticides to specific areas on insects, etc.

deJ II-140

D-59. Dubrow, B.

"Long Range Research on Pyrotechnics: Statistical Description at Particle Size and Distribution of Atomized Magnesium Powder," ORDTA, Picatinny Arsenal Project No. TA 2-9201A, Report No. 9, July 16, 1952.

D-60. Duffie, J. A., and W. R. Marshall

Factors Influencing the Properties of Spray-Dried Materials. J. A. Duffie (Office of Naval Res., Chicago Branch) and W. R. Marshall, Jr. (Univ. Wisconsin, Madison. Wis.). Chem. Engng. Progress, Vol. 49, No. 8, Aug. 1953, pp. 417–423, and No. 9, Sept. 1953, pp. 480–486, 25 fig., 5 tabl., 19 ref.

A vertical, cylindrical, co-current-flow spray dryer, 8 in. dia.× 20 ft. high was used for experiments on drying of a stream of controlled-size drops. A viscous-jet atomizer was used to produce the drops; jet breakup was studied with high-speed motion pictures. Theories of jet breakup and evaporation are reviewed, based on: RAYLEIGH 1878; SHERWOOD and WILLIAMS 1941; RANZ and MARSHALL 1952; and MARSHALL and SELTZER 1950. Experimental equipment is illustrated and described; procedure explained in detail; test run conditions tabulated. Bulk densities of several spray dried materials were studied as a function of air and feed temperature, feed concentration, and material properties. Materials included: inorganic salts, an organic dyestuff, whole milk, gelatin, coffee extract, and corn syrup. Bulk density of spray dried dyestuff, sodium chloride, and sodium silicate was found to decrease with increasing drying air temperature, with increasing liquid-feed temperature, and feed concentration, mainly due to increase in dried-particle size. The resulting particles were examined regarding their appearance, hollowness, mode of fracture under pressure, relative bulk density, and probable degree of dustiness as evidenced by friability. Photomicrographs of some of the products are own.

deJ II-141

D-61. Dunne, B., and B. Cassen

4864. VELOCITY DISCONTINUITY INSTABILITY OF A LIQUID JET. B.Dunne and B.Cassen.
J. appl. Phys., Vol. 27, No. 6, 577-82 (June, 1956).

The instability of a high-speed liquid jet with a velocity which has a transient rise followed by a linear decay with time is studied experimentally and theoretically. The jet is produced experimentally by subjecting a liquid reservoir to a shock-wave pressure. Using a shadowgraph technique, in an interval of 30 μsec four successive ¼ μsec exposures were taken using jets of water and ethanol in external atmospheres of air and helium. It is found theoretically that a velocity discontinuity is advanced through the jet at a velocity which is the mean of the instantaneous particle velocities immediately in front of and behind the discontinuity. The discontinuity consists of a thin disk of liquid normal to the jet axis. Nodules previously observed on high-speed liquid jets can be explained by this mechanism.

PA 59-4864

D-62. Dunne, B., and B. Cassen

7157. Some phenomena associated with supersonic liquid jets. B. Dunne and B. Cassen. *J. appl. Phys.*, 25, 569–72 (*May*, 1954).

Supersonic liquid jets were produced in air by means of a spring-loaded injector. At high jet velocities another type of breakup seems to occur besides the classical Rayleigh surface tension breakup, and the sinuous aerodynamic breakup. Rotationally symmetric waves are formed, and appear to "break" analogous to wind-produced waves on a body of water. The rate of cavitation of jets in water was studied for several jet velocities above the speed of sound in air.

PA 57-7157

D-63. Dunskiy, V. F.

"Coagulation During Atomization of a Liquid," V. F. Dunskiy. Soviet Phys. Tech. Phys. 1, 1932-9 (1957) (English translation); Zhur. Tekh. Fiz. 26, 1262-8 (1956).

CA 52-3465h

D-64. Dunskiy, V. F.

Dunskiy, V. G.
COAGULATION IN THE MECHANICAL DISPERSION OF LIQUIDS (Koagulatsiya pri Mekhanicheskom Raspylenii Zhidkostey). 3 Oct 60, 18p. (3 figs. omitted) 8 refs. Trans. V-1618.
Order from LC or SLA mi$2.40, ph$3.30 61-13802

Trans. of mono. Aerozoli v Sel'skom Khozyaystve, Moscow, 1956, p. 64-76.

Coagulation of the polydispersible droplet system formed during liquid dispersion was investigated by analyzing the steady-state gas flow with suspended droplets of different sizes. Experiments were made on the dispersion of several liquid sprays differing only in quantity. Results confirmed the role of coagulation during mechanical dispersion under conditions of small specific consumption of the dispersed gas and high velocity of the gas. Coagulation is most intensive in the high droplet concentration zones and at highest velocity (i.e., closest to the jet nozzles). Coagulation increases polydispersibility. The small specific flows of dispersible gas are characteristic of agricultural aerosol machines.

T 5-408

D-65. Dunskiy, V. F., and A. V. Kitayev

Dunskiy, V. F. and Kitayev, A. V.
ELECTROSTATIC SPRAYING (Elektrostaticheskoye Opryskivaniye). June 59 [7]p. RTS no. 1033.
Order from LC or SLA mi$1.80, ph$1.80 59-18160

Trans. of Zashchita Rastenii ot Vrediteley i Bolezney (USSR) 1958 [v. 3] no. 4, p. 17-18.

T 2-381

D-66. Dunskiy, V. F., et al.

Dunskiy, V. F., Yuzhnyy, Z. M., and Khokhlov, D. N.
INVESTIGATING THE PROCESS OF THERMO-MECHANICAL FOG FORMATION (Issledovaniye Protsessa Termomekhanicheskogo Obrazovaniya Tumana). 27 Sep 60, 26p. 4 refs. Trans. V-1615. Order from LC or SLA mi$2.70, ph$4.80 61-13800

Trans. of mono. Aerozoli v Sel'skom Khozyaystve, Moscow, 1956, p. 28-45.

Field methods, using the EAU-1 experimental aerosol installation, were elaborated for measuring (1) the dispersibility of thermomechanical semidispersible aerosols, and (2) toxicant concentration in semidispersible aerosol and the degree of evaporation of liquid preparations in the generator. Thermomechanical aerosol formation and the relation of dispersibility and evaporation to the basic parameters of the process were studied. It was shown that dispersible aerosol composition can be determined from the degree of liquid evaporation in the generator. During thermomechanical aerosol formation toxicant redistribution occurs, depending on physiological properties of the toxicant and solvent. Reference is made to insecticidal application.

T 5-381

D-67. Dyatlov, A. V., and S. F. Khokzlov

4294. Dyatlov, A. V., and Khokzlov, S. F., On the theory for disk sprayers (in Russian), *Trudi Dnepropetr. Khim.-Tekhnol. In-ta* no. 10, 27-36, 1960; *Ref. Zh. Mekh.* no. 9, 1961, Rev. 9B 227.

Some questions are discussed dealing with the theory of disk sprayers of liquids which enable an approach to be made to the calculations for this type of sprayer. An investigation is made of the stationary flow of the liquid from the center to the periphery of the rotating disk. A nonlinear differential equation is obtained for the motion of the liquid in vector form and in polar coordinates. Results are given for the numerical integration of the equation; graphs are furnished for the changes of radial acceleration and of angular velocity of particles of the liquid in relation to time, and of the absolute and relative trajectory of the motion of the particles of liquid on the disk. The motion is examined of a very thin layer of liquid over a smooth disk. An approximate solution of the problem is obtained when the principle for the distribution of the velocities by the height of the layer of liquid is assigned. The case is analyzed of the motion of a liquid over a disk with radial channels which prevent slip of the liquid. Formulas are obtained for the trajectories, the duration of the motion along a channel and the radial velocity of a particle of liquid when shot off the disk. A formula is given for the calculation of the power of the motor which gives the disk its rotational motion, and also a formula for the calculation of the productive capacity of a disk sprayer.

AMR 16-4294

E-1. Echols, W. H., and J. A. Young

N63-23170 Naval Research Lab., Washington, D.C.
STUDIES OF PORTABLE AIR-OPERATED AEROSOL GENERATORS
W. H. Echols and J. A. Young July 26, 1963 18 p
(NRL-5929) OTS: $0.50

These generators are used to produce polydisperse liquid aerosols. At a given pressure and the consequent flow rate, the polydispersion produced by each generator is reproducible both in terms of particle-size distribution and aerosol mass concentration, but each generator model differs significantly from the others in total aerosol output as well as particle-size distribution at the same operating pressure. The only requirements for operation of the aerosol generators are an adequate, filtered, and well-regulated compressed air supply and the liquid to be disseminated. When DOP (di(2-ethylhexyl)-phthalate) is used as the liquid, the dispersed phase of the aerosol system has a light-scattering geometric mean diameter of the magnitude of one-half micron.

N63-23170, 24-17

E-2. Eichborn, J. L. von

Dispersoidanalyse von Aerosolen und Suspensionen in Gasen (Dispersoid analysis of aerosols and suspensions in gases). Johann Ludwig von Eichborn (Agriculture Dep., Univ. Göttingen, Germ., Prof. K. Gallwitz, Dir.). Mimeogr., Univ. Göttingen, Germ. (1953). 132 p.

This is a systematic survey of the physical and chemical principles, and present status of knowledge, of dispersoids in gases, arranged according to decimal classification, in four main chapters:

I. Production and generation of aerosols (fogs, smokes), powders and dusts (from liquids, solids, and gas reactions, incl. combustion) (pp. 1–7). Treats sprays produced by impact and centrifuging, by breakup of jets and moving drops, from mixtures and solutions, by ultrasonic and by electric means. Discusses testing methods and special applications.

II. Physical and colloid-physical behavior of aerosols and powders (without change of state), pp. 1–48. Treats stability of aerosol suspensions in the state of rest (Brownian motion and diffusion), isothermal coagulation and diffusion, and thermal diffusion. Discusses behavior of suspensions in a gravity and in a centrifugal field, sedimentation, diffusion path, superimposition of sedimentation and coagulation. Flow of suspensions with and without obstacles, incl. filtration, spraying, elutriation, sieving, behavior in acoustic field, in electrical field, in low-frequency, high-frequency, and radar wave fields, and under the influence of light waves.

III. Colloid-chemical and chemical behavior of aerosols and powders, pp. 1–21. Treats interaction of aerosols and powders with gases and vapors, and interfacial effects of gas bubbles with liquids, change of state of the particles and their media, chemical and electrochemical effects.

IV. Dispersoid analysis of aerosols and powders, results, processes, auxiliary means, pp. 1–56. Survey of particle size distribution, statistical methods, sample taking, size and shape of particles, weight and volumen concentration, surface area, pore volume, permeability. Measurement by diffraction, reflexion and absorption of light. Micro-scopy, -photography, -projection, ultra- and electron-microscopy, photo-electric registration of particles. Fractionation according to particle movability in the dispersion fluid; sedimentation by gravity, by centrifugal force, and by electric field. Behavior of aerosols in diffusion, in narrow pipes and filters, thermodiffusion, behavior in acoustic field. Fractionating according to evaporation velocity, and according to concentration-dependent properties (mechanical, electrical, optical). Peptisation and emulgation.

Author supplements this systematic framework with succinct description of each concept, method, property, and principle; he also lists the authors treating the individual subject and item; gives large number of bibliographic data, with author, title and year.

deJ I-86

E-3. Eichler, O.

"Apparatus for Producing a Fog [Aerosol] of Sulfuric Acid and Other Similar Substances. O. Eichler (Univ. Heidelberg, Ger.). Arch. Intern. Pharmacodynamie 133, 10-15 (1961) (in German).

CA 56-2669h

E-4. Einbinder, H.

The Theory of Particle Impaction and Its Application to the Design of Cascade Impactors. Harvey Einbinder, Tech. Rep. Battelle Memorial Institute, No. 2409. 1 March 1955. pp. 1–26, 4 fig., 16 ref.

Impaction of particles in moving gas stream upon solid surfaces is considered. Analytic method, by successive approximation, for computing the trajectory of particle. General formulas are obtained for the trajectory, these are then applied to the impaction of particles in a normally incident rectangular jet located at infinite distance from a collecting plane. – Principal operating characteristics of the cascade impactor, with circular jets, and collecting slides, are discussed. Formulas are given for the jet sizes which will produce the described sizegrading of aerosols. Special case is treated where sonic velocities are attained in the last jet so that it acts as a limiting flow orifice, which sets a limit on the smallest size particle that can be impacted; this is of practical importance in collecting small particles of about 0.5 micron in diameter from a dilute aerosol. – Resolving power of the cascade impactor can be greatly improved by moving the jet close to the collecting surface, which is advantageous in analysing the mass distribution of areosols with limited size range. Thereby it is necessary to determine experimentally the fraction of particles impacted as a function of the impact parameter.

deJ I-86

E-5. Eisenklam, P.

5757. Eisenklam, P., Atomisation of liquid fuel for combustion, *J. Inst. Fuel* 34, 243, 130–143, Apr. 1961.

The Imperial College of Science and Technology, High Speed Fluid Kinetics Laboratory, has been engaged for several years past in the study of liquid fuel atomization. The present paper summarizes the results of this work as it pertains to spray combustion; it also points out gaps in existing knowledge on the mechanism of combustion, component elements of which are: reaction chemistry, mass transfer (evaporation), fluid flow or mixing. Atomization is one way of preparing a liquid fuel for evaporation. The atomizer disintegrates the liquid, and projects and disperses it in the preferred direction. The drops produced in the vicinity of the atomizer form the "initial spray" and they diminish in size during their flight; drops within the combustion chamber at any instant form the "resident spray" whose mean drop size and size dispersion are different from those of the initial spray. First chapter, on mass transfer from sprays, treats rate of vaporization, interfacial area, concentration gradient, and mass-transfer coefficient; for all those subjects clear mathematical expositions are given; previous research work is reviewed in considerable detail. A chapter on formation of drops discusses instability of liquid sheets and drops, shatter of drops and their coalescence, with typical photos, and includes surveys of previous work.

Another chapter, on atomizing devices, describes the characteristics of pressure atomizers, rotary atomizers, and twin-fluid atomizers. The following chapter, on the performance of atomizers, deals with flow rate, spatial configuration of the spray, drop size, determination of drop size and drop-size distribution, and performance of sprays obtained from atomizers of various types. A rather extensive bibliography is given of the more important papers published during the past ten years or so, including some still earlier publications, which is a useful guide for those desiring more detailed information on some of the topics discussed. But even without such collateral reading, the present extensive paper should give a clear and up-to-date orientation on the present status of the subject, and a good introduction for further study.

AMR 14-5757

E-6. Eisenklam, P., N. Dombrowski, and D. Hasson

"Drop Formation from Rapidly Moving Liquid Sheets," Imperial College Rpt. JRL No. 14 23 p. + figs., May, 1959.

E-7. Eisenklam, P., and P. C. Hooper

"The Flow Characteristics of Laminar and Turbulent Jets of Liquid," Imperial College Report JRL42, 1958.

E-8. Eknadiosyants, O. K.

"The Kinetics of Ultrasonic Fog Formation," Soviet Phys. - Acoustics 9, no 2, 201-2, (Oct-Dec 1963).

E-9. Ellis, J. E.

"The Atomization of Liquids," Ph.D Thesis, The Imperial College, London. 1950

E-10. Ellis, J. E.

"A Study of the Flow of Fluids Through Swirl Atomizers," Agricultural Res. Council 275/51 (1950).

E-11. Engel, O. G.

5494. **FRAGMENTATION OF WATERDROPS IN THE ZONE BEHIND AN AIR SHOCK.** C.G.Engel. J. Res. Nat. Bur. Stand., Vol. 60, No. 3, 245-80 (March, 1958).

Observations made on the fragmentation of two waterdrop sizes, after collision with air shocks that were moving at three different supersonic velocities, are reported. The possible mechanisms of various aspects of the fragmentation process are discussed. The experimental observations indicate that high-speed-rain-erosion damage should not be observed on spheres having a diameter as large as 4 feet and moving with a Mach number in the range of 1.3 to 1.7 in rain that has a drop diameter of 1.4 mm. Waterdrops of this size should be reduced to mist in the zone of separation between the detached shock and the surface of the sphere according to the results that are reported. A means to extend this protection to spheres of smaller diameter or to rain of larger size is pointed out. The need for further experimental observation of the time required for the fragmentation of waterdrops using shocks moving at higher Mach numbers is indicated to verify and extend the information.

PA 61-5694

E-12. Engelhard, H.

Entwicklung der Aerosol-Grundlagenforschung zwischen 1930 und 1954; Übersichtsreferat (Development of basic research on aerosols between 1930 and 1954; a survey report). H. Engelhard (Göttingen, Germ.). Zschr. Aerosol-Forsch. u. -Therapie, Vol. 8, No. 3, March 1960, pp. 290–345, 25 fig., 12 tabl., over 500 ref.

Brief reports on various aspects of aerosol research in the stated period, with extensive bibliographies for each section. Introductory chapter deals with importance for military applications, hygienic aspects of atmospheric contamination particularly in mining and in dusty industries, and with agricultural application in pest, fungus, and insect control (27 ref.). Chapter on aerosol production (106 ref.) treats thermodynamic aspects, evaporation, and production of uniform aerosols for testing purposes (by atomization, explosion, and condensation). Chapter on properties of aerosols (120 ref.) deals with a) coagulation, b) inertial forces in motion and precipitation on surfaces, c) vibration and acoustic effects. Other chapters deal with electrical properties (37 ref.), ultrasonic effects (35 ref.), light scattering and refraction effects (75 ref.). Analytic methods, by turbidimetry, by cascade impactor, by sedimentation, and by electrostatic counting (80 ref.), filtering (53 ref.), and precipitation (33 ref.) have been treated in separate sections.

deJ II-159

E-13. Epstein, B.

The mathematical description of certain breakage mechanisms leading to the logarithmico-normal distribution. Epstein, B. *J. Franklin Inst.*, 244, 471-7 (*Dec.*, 1947).—If the distribution of particle size in an ideal aggregate can be assumed to be the result of a large number of successive random subdivisions then it will be approximately lognormal. The author gives a fairly simple mathematical treatment of the problem.

PA51-2299

E-14. Ericksen, J. L.

Thin Liquid Jets. Jerald L. Ericksen (Appl. Math. Br., Mech. Div., Naval Res. Lab., Washington, D.C.). Jl. Rational Mech. and Anal., Vol. 1, No. 4, 1952, pp. 521–538, 1 fig., 15 ref. (with titl.).

Refers to Savart's experiments on thin liquid sheets (water bells), and to the theoretical explanation of these by Boussinesq. These dealt with the case where the streamlines are meridians on a surface of revolution, and predicted that, in absence of body forces the streamlines will be catenaries. Present study deals with stability of water bells which are not axially symmetric, and provides a solution for a limited class where the body force vector is constant. Considers stationary motion of a liquid jet in a homogeneous medium which is at rest. Headings: formulation of problem; equation of motion; an initial-value problem; properties of the solutions of the equations of motion; pseudo-plane flow; an infinite family of solutions; axially symmetric flow. Refers to: D. Spatano: Idromeccanica, Vol. 1, libro 1, pp. 307–444 (publ. HOEPLI, Milano, 1915).

deJ II-162

E-15. Esche, R.

Ultraschall-Raumaerosole, ihre Erzeugung und ihre physikalischen Eigenschaften (Ultrasonic space aerosols, their production and their physical properties). R. Esche (Erlangen, Germ.). Z. f. Aerosol-Forschung u. -Therapie, Vol. 4, No. 5, Dec. 1955, pp. 448–452, 6 fig.

A 20-watt ultrasonic generator, having a $BaTiO_3$ crystal swinger focussed at the liquid surface, produces capillary waves therein, which break up the surface into droplets of about 1 micron size. Six of these generators, arranged in a circle and provided with a central fan, were found adequate for a room of 1600 cu.ft. size. Fog density as function of time, and droplet-size spectrum, are represented in graphs; shows photo of the commercial form of the instrument.

deJ II-162

E-16. Euteneuer, G. A.

4288. Euteneuer, G. A., Drop size and throw distance of jet sprays as functions of pressure (in German), *VFDB-Zeitschrift* **6**, 3, 124–128 + 9 *figs.*, *Aug.* 1957.

Experience has shown that the increase of the throwing distance of a broken up liquid jet will reach a limit beyond which an increase of pressure does not result in increased throwing distance; in fact, in the case of wide-angle conical jets increasing pressure may decrease the throwing distance. These effects have been investigated from the aspect of fire fighting. Drop size, throwing distance, air resistance, rate of discharge, etc., depend on the pressure. These values and the nozzle design influence the efficiency of discharge. Equations have been derived based on simplifying assumptions, which are also represented graphically, showing the maximum throwing distance as a function of pressure, nozzle diameter, and shape of spray (large and small cone angle). These show a qualitative agreement with experimental results.

AMR 11-4288

E-17. Euteneuer, G. A.

472. Euteneuer, G. A., Influence of surface tension on the development of hollow liquid jets (in German), *Forsch. Geb. Ing.-Wes.* (B) **22**, 4, 109–122, 1956.

Hollow liquid jets can be produced in two ways: (1) by means of nozzles having an annular orifice whereby the walls of the orifice may form a cylinder or a cone, and (2) by means of cylindrical nozzles in which, in the upstream portion, a rotation is imparted to the flowing liquid, which, on its exit from the nozzle, is driven radially outward by the centrifugal force. Author calculates the form of jet under the simplifying assumption of frictionless flow. The contour of the jet, as determined by the dimensions of the nozzle, the efflux velocity, and the density and surface tension of the liquid, agreed substantially with the observed values, up to the point at which the jet disintegrated. At low efflux velocities it can happen that the jet closes up again after a certain travel, owing to the influence of the surface tension, and no atomization takes place. By suitable grouping of the influencing quantities there remain, as parameters for the jet contour, only the Weber number, the radius of the nozzle, and the cone angle of the orifice.

The calculations are executed for water and for fuel oil. The experiments were made with a nozzle having adjustable vanes in the flow passage whereby the rotation imparted to the liquid could be varied. A central tube was provided for admitting air to the inside of the hollow jet. The decrease of kinetic energy along the jet surface owing to the work absorbed by the surface tension is calculated.

AMR 10-472

F-1. Falk, D. M.

"Atomization of Liquids Upon Impingement of Opposed Jets," Mass. Inst. Tech., Dept. Chem. Engr., M. S. Thesis, Sept. 12, 1947.

F-2. Fedoseyev, V. A.

534. Fedoseyev, V. A., The atomization of a jet of superheated fluid (in Russian), *Kolloidn. Zh.* **20, 4,** 493-497, 1958; *Ref. Zh. Mekh.* no. 7, 1959, Rev. 7626.

Experiments are described in which the atomization of a fluid was performed by preheating it. If a jet of a superheated fluid is released into the atmosphere, vapor droplets (bubbles) will form in the liquid, thereby stretching the latter into thin films the breakdown of which leads to the formation of fine droplets. Simultaneously with this atomization, by the excess heat supplied in superheating, the droplets are caused to evaporate, which promotes their reciprocal repulsion.

It is found that the size of the droplets obtained in atomizing a jet of a superheated liquid depends on the degree of superheating of the latter and the size of the discharge nozzle, but is little influenced by the shape thereof. It is shown that the radius of these droplets is inversely proportional to the vapor pressure in the vessel in which the superheating of the liquid takes place and directly proportional to the diameter of the nozzle. It is observed that the atomization of a superheated liquid is completed only at a considerable distance from the nozzle.

AMR 15-534

F-3. Ferrie, F., and N. Manson

10486* Standardization of Micrographs of Atomized Jets. (French.) Frank Ferrie and Numa Manson. *Comptes Rendus hebdomadaires des Séances de l'Académie des Sciences*, v. 234, June 4, 1952, p. 2254-2256.

Proposes method of standardization by which the real volume of a jet, the number of drops in this volume, and their diameter can be ascertained. Describes experimental arrangement. Results are charted and discussed.

BMI 1-10 486

F-4. Filintsev, G. P., et al.

"The Spray Drying of Ceramic Suspensions." G. P. Filintsev, T. I. Taraeva, A. E. Alesovitskiĭ, and I. M. Mikheev. Steklo i Keram. 17, No. 7, 18-21 (1960).

CA 54-23237b

F-5. "Measurement of Particle-size Distribution in Aerosols." Morris A. Fisher (Illinois Inst. of Technol., Chicago). J. Soc. Cosmetic Chemists 7, 77-85 (1956).

CA 50-6709f

F-6. Fogler, B. B., and R. V. Kleinschmidt

"Spray Drying," Ind. Eng. Chem. 30, 1372 (1938).

In spray drying, a solution or slurry containing the desired solid material is continuously sprayed into a chamber and subjected to the action of a stream of drying gas, usually preheated air or diluted products of combustion.

One of the most important aspects of the process is the physical form of the product, which is usually granular; the individual particles are generally rounded in shape and hollow to a degree which is controllable over a rather wide range in the operation of the process. For many materials a product in this form has important advantages, chief of which are rapid solubility, lessened hygroscopicity, and unusual mobility in handling. The hollow form of the spray-dried particle usually gives a more bulky product than is obtained by other drying processes. This is an asset only when the spray-dried product will command a price which will more than offset the higher cost of packaging.

The other important advantage of spray drying is the rapid rate and relatively low material temperature at which drying is accomplished. From 15 to 30 seconds is a fair estimate of the time a particle stays in the spray-drying chamber when passing from liquid to solid form; the particle temperature need not rise materially above the wet-bulb temperature of the liquid of the solution. This makes the process particularly adapted to the drying of heat-sensitive materials, some of its most important applications being the drying of milk, eggs, potato flour, soap, and blood.

Author

F-7. Foster, H. H., and M. F. Heidmann

1127. Foster, H. H., and Heidmann, M. F., Spatial characteristics of water spray formed by two impinging jets at several jet velocities in quiescent air, *NASA TN D-301*, 34 pp., July 1960.

Sprays formed by two 0.089-in. impinging water jets in quiescent air were studied, in the velocity range of 30 to 74 ft/sec, corresponding to that of current rocket engines. Atomizers were same as used in previous combustion tests. The point of jet impingement was surveyed photographically. Spray velocity varied from 99 to 72% of jet velocity in a circumferential survey around the point of impingement. One half of the mass was distributed within 40-degree included angle about the spray axis. Mass mean drop size was about 54% of the extrapolated maximum of 1800 to 2400 microns; the maximums occurred along the spray axis. Experimental apparatus is described; sample spray pictures are shown; typical spray distributions are represented in tables and charts.

While this research itself was directed to clear up fuel combustion phenomena in rockets, the experimental method and equipment have a more general interest and applicability. AMR 14-1127

F-8. Fraser, R. P.,

Fraser, R. P., "Liquid Atomization," J. Roy. Aero. Soc. 65, 611, 749-750, Nov. 1961.

F-9. Fraser, R. P.

2192. Fraser, R. P., The important functions of the spray nozzle, *Commonwealth Phytopathological News, Kew, England,* 3, 1, 3-6, Jan. 1957.

The spray nozzle or atomizer is a device to accelerate and disintegrate the liquid; first by producing a liquid sheet from which drops will be produced, and secondly by dispersing the resulting drops in a controlled pattern and direction. Spraying is a complex physical phenomenon because of: (a) the large number of dimensional variables in the atomizer nozzle itself; (b) the variation in physical proper of the liquid sprayed and in the hydraulics of the flow; (c) the changes in the ambient surroundings of the spray. Different applications call for different drop sizes, e. g., aerosols for space sprays require drop sizes from 1 to 30 microns, fungicidal sprays 100 microns, weed killers of 100 to 300 microns; long-distance spraying in orchards may require drop sizes of 1500 microns to reach the distance required. For each application a number of nozzle sizes and designs is required to obtain the desired effect. There is no universal nozzle for all purposes, though nozzles can be designed with interchangeable parts to satisfy different spraying requirements.

Flash photos are shown of sprays from accurately manufactured nozzles yielding uniform-size droplets and even distribution, a from damaged nozzles yielding uneven droplets and distribution. Also sprays of distilled water with normal surface tension, and of tap water with surface active agent admixture are shown, the latter having a wider angle and more rapid disintegration. Similar changes can be observed in spraying slurries containing solid materials. Much can be done for controlling drop size by manipulating the physical properties of the spray mixture.

AMR 11-2192

F-10. Fraser, R. P.

2189. Fraser, R. P., Liquid fuel atomization, Sixth Symposium (International) on Combustion, Pittsburgh, Pa., Aug. 19-24, 1956, 687-701.

In liquid fuel combustion the object of the atomizer is to disintegrate the fuel into the smallest drops possible to increase the specific surface of the liquid and thus the rate of mixing and vaporization. The functions of the atomizer are to accelerate and disintegrate the liquid by the production of a liquid sheet from which threads and finally drops are produced, and also to disperse the resulting drops in a controlled pattern and direction. Author discusses classification of atomizers; effect of spraying atmosphere on drop size; table of viscosities for various liquids; drop size from pressure atomizer; atomization by means of a second fluid (twin-fluid atomizers); detailed diagrams of sprays issuing from vortex cup atomizers showing isobar lines; rotary atomizers. Of particular value is the concise analysis of previous researches on atomization, from Rayleigh's early work to present time.

AMR 11-2189

F-11. Fraser, R. P.

High Speed Photography in Fluid Kinetics. R. P. Fraser (Imper. Coll. of Sci. and Techn., London). Jl. of Photographic Science, Vol. 3. 1955, pp. 21–32, 23 fig., 17 ref.

Photographic technique used in laboratories can be of three kinds, according to the manner of illumination: (1) light reflected from object, illuminated by a continuous source, intermittent source, or single flash; (2) light transmitted past or through object to give a shadow; (3) light emitted by self-luminous objects, such as flames or arcs. With each form of illumination the record may be a single photograph, a series, or a continuous graphical record on a moving film in a chronograph camera. Details of these methods are described. Examples taken from the work of author's laboratory are given, with sample photos, from investigations of (a) detonation wave (using Schlieren shadow technique); (b) supersonic flow through model nozzles; (c) air discharge through a twodimensional nozzle with straight sides and with curved sides; (d) formation and projection of liquid jet; (e) disruption of liquid jet in flight; (f) formation of drops from a sheet of liquid of various surface tensions; (g) velocity distribution in a liquid sheet from a fan spray using a doubleflash apparatus described in TURNER 1957.

deJ I-101

F-12. Fraser, R. P., and N. Dombrowski

The Dependence of Interpretation on Photographic Technique in Fluid Kinetics Research. R. P. Fraser and N. Dombrowski (Imper. Coll. of Sci. and Techn., London). High Speed Photography (Proc. Third Internat. Congr., Sept. 1956, edited by R. B. Collins), Butterworths Sci. Publ., London, pp. 376–384, 5 fig., 8 ref.

Study of fast physical processes by high-speed photography often requires more than one method of lighting to obtain the needed information. Moreover, the exposure time may have to be varied from microseconds to centiseconds, with application of double exposure, streak, and interferometric techniques. Authors give illustrations of four different techniques of lighting (diffuse reflection, diffuse transmission, specular reflection, and parallel transmission), and of exposures in the study of disintegration of liquid sheets leaving a spray nozzle.

deJ I-102

F-13. Fraser, R. P., and N. Dombrowski

8434. High-speed photography in the study of moving fluids. R. P. FRASER AND N. DOMBROWSKI.

Royal Photographic Society International Conference [London] 360-70. See Abstr. 7586 (1955).

Outlines the techniques and contains references and photographs on: (*a*) sheets of liquid in the process of disintegration showing the influence of liquid properties on the manner of disintegration, taken during a study of the mechanics of spray nozzles; (*b*) supersonic jet streams of air travelling at Mach 3 and 4, taken during a study of the flow in supersonic nozzles; (*c*) the detonation wave in gases, taken during a study of the spinning detonation wave in tubes.

See also Schultze, R. S. (1955)

PA 58-8434

F-14. Fraser, R. P., N. Dombrowski, and P. Eisenklam

5330. Vibrations as a cause of disintegration in liquid sheets. R. P. Fraser, N. Dombrowski and P. Eisenklam. Letter in *Nature* [*London*] 173, 495 (*March* 13, 1954).

A study of the disintegration of liquid jets by a pressure-atomiser shows that the liquid first forms a thin sheet which disintegrates away from the nozzle, the disintegration being influenced by the properties of the liquid, the nozzle and the surrounding atmosphere. In some cases, holes are formed in the sheet and these expand rapidly. The holes can be caused by the presence of non-wettable particles in the liquid or by turbulence. With liquid jets, turbulent, unsteady flow behind the nozzle is a primary cause of jet disintegration. The frequency of ripples observed in the sheet is of the order 10 kc/s.

PA 57-5330

F-15. Fraser, R. P., N. Dombrowski, and J. H. Routley

"Production of Uniform Liquid Sheets from Spinning Cups," Chem. Eng. Sci. 18, 315-21 (1963).

Abstract—An investigation has been made of the effect of liquid flow disturbances within a spinning cup on the uniformity of the sheet centrifuged from its lip. It has been found that, except for a limited range of operating conditions, a spinning cup is not capable of smoothing out the flow of liquid over its surface solely under the action of centrifugal force, and the sheet uniformity is critically dependent on the method of feed distribution, feed rate and viscosity. When the feed is stationary with respect to the cup and the flow rate is greater than 200 lb/hr and/or the viscosity is less than 40 cS, upstream flow disturbances produced as the liquid impinges on the cup walls propagate along the walls to the lip with consequent detriment to the sheet uniformity. Where the feed distributor rotates with a cup and is designed to distribute the liquid uniformly into a damping reservoir at the back of the cup, uniform sheets are produced over a wide range of operating conditions.

Author

F-16. Fraser, R. P., N. Dombrowski, and J. H. Routley

"The Filming of Liquids by Spinning Cups." Chem. Eng. Sci. 18, 323-37 (1963)

Abstract—An investigation has been made of the flow characteristics of sheets produced from spinning cups.

Expressions are presented and experimentally confirmed for the conditions of sheet formation, and for the variation of sheet thickness from the vicinity of the cup lip to the region of free disintegration. At a distance of more than about ½ in. from the cup lip the sheet thickness is independent of lip angle and liquid viscosity, and depends only on the cup diameter and rotary speed and flow rate.

Two principal mechanisms of sheet disintegration have been established: one which occurs at relatively low peripheral speeds and liquid flow rates, and the second at higher peripheral speeds and liquid flow rates.

Author

F-17. Fraser, R. P., N. Dombrowski, and J. H. Routley

"The Atomization of a Liquid Sheet by an Impinging Air Stream," Chem. Eng. Sci. 18, 339-53 (1963)

Abstract—An investigation has been carried out into the processes of drop formation from liquid sheets of controlled thickness by an air blast at approximately 90°. The results may be summarized as follows:

1. A liquid sheet does not break down upon immediate impact with the air stream but is deflected away from it. Waves are initiated at the point of impact and the sheet breaks down into drops through the formation of unstable ligaments.
2. The resulting drop size is a function of, *inter alia*, the sheet thickness. Thus the production of thin liquid sheets is an essential pre-requisite to fine atomization.
3. A semi-empirical relation has been derived which satisfactorily correlates mean drop size with sheet thickness for a wide range of operating conditions.

Author

F-18. Fraser, R. P., N. Dombrowski, and J. H. Routley

6172. Fraser, R. P., Dombrowski, N., and Routley, J. H., The mechanisms of disintegration of liquid sheets in cross-current air streams, *Appl. Sci. Res.* (*A*) 12, 2, 143-150, 1963.

A photographic study is made of the disintegration of thin (88 to 133 microns) circular water sheets in air streams flowing normal to the liquid sheet. Disintegration occurs by (1) the formation of circumferential waves with fragments of the sheet being torn off and atomized, and (2) the setting up of a vibratory system in which the sheet breaks up by resonance between the two fluids into periodic clusters of drops. The wave mechanism is found to occur with air/liquid momentum ratios below 18, and the vibratory mechanism above this value. Wave disintegration is found to produce smaller drops than with the vibrating sheet. At any level of air energy atomization is improved when the air is distributed from a narrower annular gap, the air stream being utilized more efficiently. Spatial drop dispersion in the atmosphere is affected by the mechanism of disintegration, the drops being relatively widely dispersed in wave disintegration but forming a rather dense core along the nozzle axis in vibratory disintegration. Imparting a rotary motion to the atomizing air stream improves the quality of atomization and spatial dispersion, particularly with vibratory disintegration.

AMR 17-6172

F-19. Fraser, R. P., N. Dombrowski, and J. H. Routley

"Performance Characteristics of Rotary Cup Blast Atomizers," R. P. Frazer, N. Dombrowski, and J. H. Routley (Imp. Coll. Sci. Tech., London). J. Inst. Fuel 36 (271), 316-29 (1963).

CA 59-13749h

F-20. Fraser, R. P., and P. Eisenklam

1837. Fraser, R. P., and Eisenklam, P., Liquid atomisation and the drop size of sprays, *Trans. Inst. chem. Engrs.* **34, 4,** 294-319, 1956.

Paper consists of a survey of the fields of atomization and the major spraying applications of interest to the chemical engineer. It deals with drop-size determination analysis and the influence of atomizer, design, liquid property, and ambient pressure on the drop size of a spray.

AMR 10-1837

F-21. Fraser, R. P., and P. Eisenklam

15265 Research Into the Performance of Atomisers for Liquids. R. P. Fraser and Paul Eisenklam. *Imperial College Chemical Engineering Society, Journal,* v. 7, 1953, p. 52-68. Brief summary of research over the past 8 years. Photographs, diagrams, graphs, tables. 11 ref.

BMI 3-15265

F-22. Fraser, R. P., P. Eisenklam, and N. Dombrowski

4287. Fraser, R. P., Eisenklam, P., and Dombrowski, N., Liquid atomization in chemical engineering, Reprinted from *Brit. chem. Engng., London* 2, Aug., Sept., Oct., Nov. 1957. 23 pp.

After a concise survey of the broad fields of application of sprayed liquids in combustion, agriculture and chemical engineering and the wide range of physical properties of liquids to be atomized, authors present a classification of atomizers, and discuss the mechanism of disintegration, spray sheet development, expansion of liquid surfaces, drop sizes from atomizers, and effect of ambient conditions. Detailed treatment is accorded to three main groups of atomizers: (a) Rotary (liquid flow equations and relationships, processes of drop formation, drop sizes, and drop penetration); (b) pressure nozzles (classification into subgroups of single-orifice, impinging-jet, deflector-nozzle, and swirl types, energy requirements and efficiency of atomization, performance, discharge coefficient, size of spray sheets, drop-size, and spatial dispersion); (c) twin-fluid atomizers (process of drop formation, drop size relationships with different viscosities, and energy utilization). The types of nozzles are illustrated in clear cross-sectional drawings, and the relationships are given by equations and in charts.

AMR 11-4287

F-23. Fraser, R. P., et al.

"Drop Formation from Rapidly-moving Liquid Sheets," R. P. Fraser, Paul Eisenklam, Norman Dombrowski, and David Hasson (Imp. Coll., London). A. I. Ch. E. (Am. Inst. Chem. Engrs.) J. 8, 672-80 (1962).

CA 58-4187b

F-24. Friedman, S. J., F. A. Gluckert, and W. R. Marshall

7684 **Centrifugal Disk Atomization.** S. J. Friedman, F. A. Gluckert, and W. R. Marshall, Jr. *Chemical Engineering Progress* (Engineering Section), v. 48, Apr. 1952, p. 181-191; disc., p. 191.

Presents study of power consumption, drop size, drop-size distribution, and trajectory from a number of typical centrifugal disks operating over a wide range of conditions. Correlations developed which permit drop size and distribution from spray disks and power consumed by these disks to be predicted. Relationships proposed are in general agreement with data of other investigators. Apparatus diagrams, graphs, and tables. 36 ref.

BMI 1-7684

F-25. Fritsch, W. H.

Zur Aerodynamik des Ölbrenners (Aerodynamics of oil burners). W. Hans Fritsch (W. Schmitz und Apelt GmbH., Wuppertal, Germ.). Das Ölfeuer-Jahrbuch 1960 (Verl. Gustav Kopf und Co. KG, Stuttgart, Germ.) pp. 149 to 241, 94 fig., 28 ref. (See KNAEUSEL 1960.)

Treats basic aerodynamics of oil burners, in particular the guiding of air flow. Lists composition of air; equation of state between specific volume, temperature, and pressure; thermal and thermodynamic properties; viscosity vs. temperature; flow of air with superimposed vibrations; parallel and eddying flow; source and sink. Applies the concepts to various forms of combustion chamber. Explains the Bernoulli theorem of continuity, friction of conduit walls, resistance of elbows and constrictions, subdivision of flow, energy loss in channels, measurement of airflow, interrelation of pressure loss and air velocity. Discusses: atomizing function of air on liquid fuel; concept of flow number; experiments of droplet sizes by JOYCE, TROESCH, NUKIYAMA, and others; various types of atomizing nozzles (low-pressure, medium pressure, and high-pressure) and their fields of application. Motion of a droplet in an air stream, and terminal velocity are discussed, also behavior of flame in a rotary air stream. Considers practical aspects of air flow control, coke formation, stabilization of flame by flame holder, flame length, equation of mixing, energy requirement, mixture formation, excess air, charts of characteristic mixing number. Points out that present knowledge is incomplete, and burners are designed largely on empirical basis.

deJ II-175

F-26. Fruengel, F.

Methoden der photographischen Erfassung schneller Bewegungsvorgänge in Strahl-, Strömungs- und Werkstoff-Forschung (Methods of photographic recording of rapid motion phenomena in jet-, flow-, and materials-research). Frank Fruengel (Hamburg, Germ.). Motortechn. Zschr. (MTZ), Vol. 22, No. 5, May 1961, pp. 155–159, 14 fig., 17 ref.

Recent developments in high-speed photography provide exposure times less than 1 microsecond, and rates up to 50,000 frames per sec. Also X-ray and ultraviolet illumination can be used, to eliminate the disturbing influence of superimposed, unwanted light, e.g., in combustion studies. By transforming electric pulses into high-frequency electric spark bursts an inertia-free indicator in form of spark patterns can be obtained, by means of which air currents and flow patterns can be photographed. Shows application to slow-motion movies of traveling shock and stress waves of photo-elasticity models. Shows sequence photos of: fuel spray; water jet from a high-pressure nozzle; separation of a drop from its supporting liquid filament; X-ray sequence photos of a wire exploding into metal drops by overload with condenser discharge. References list recent pertinent literature.

deJ II-176

F-27. Fry, J. F., P. H. Thomas, and P. M. T. Smart

The Production of Fire-Fighting Sprays by Impinging Jets. J. F. Fry, P. H. Thomas, and P. M. T. Smart (Joint Fire Res. Org. of D. S. I. R. and F. O. C., Boreham Wood, Herts. Engl.). Quart. Inst. Fire Engrs. (1950), 18 pp., 13 fig., 5 ref.

In some fire-fighting nozzles the spray is formed by impinging jets; pairs of jets are arranged so that they impinge either ahead of the nozzle or radially around it; the spray may be in the form of a cone, a flat sheet, or a spherical cloud. This is a research report on sprays formed by single pairs of impinging jets, on their total flow, quantity distribution, and droplet size. Experimental equipment is illustrated and described; conical nozzles with $^1/_{16}$, $^1/_8$ and $^3/_{16}$ in. dia were used, with pressures from 20 to 120 psi. Diagrams of quantity distribution are shown; graphs are given on length of wetted area as a function of angle of impingement. Samples of sprays were collected in castor oil spread on microscope slides, and the populations represented according to the Rosin-Rammler Law. Various relationships are discussed, as: influence on particle size and specific surface (1) of velocity of impingement, (2) of jet diameter, (3) of kinetic energy.

deJ I-106

F-28. Fuchs, N. A.

Opredelenie razmera kapelek v maspian'ikh tumanakh (Determination of droplet size in oil fogs). N. A. Fuchs. Kolloidnyj Zhurnal, USSR, Vol. 11, No. 4, 1949, pp. 280–282, 2 fig., 1 tabl., 1 equ., 2 ref.

Cited in PILCHER, MIESSE, and PUTNAM 1957. Gives formula and graph for ratio of spherical droplet diameter to the flattened droplet "lens" diameter on the microscope slide, and also for relation between this ratio and the "lens" contact angle. Refers to WHITMORE 1930.

deJ II-177

F-29. Fuchs, N. A.

"The Mechanics of Aerosols," Pergamon Press, London, 408 p. Dist. by Macmillan, New York, 1964

F-30. Fuhs, A. F.

2144. Fuhs, A. E., Spray formation and breakup, and spray combustion, AFOSR TN 58-414 (Sandstrand Turbo, Pacoima, Calif., TN 4; AMF/TD no. 1(99); 129 pp. + 26 figs. + 107 refs., Feb. 1958.

Report is a survey of literature on liquid spray behavior, particularly in jet propulsion devices. Part I, (pp. 1-76), "Spray formation and breakup," discusses the known means for atomizing liquids, and the mechanisms for jet and sheet breakup under environments of non-burning media. Factors influencing spray characteristics, and the disintegration of liquid jets and sheets are discussed, based on previous researches of Haenlein, Ohnesorge, Sauter, Schnebel, York, Stubbs, and Tek, Hagerty and Shea, and others. Deformation of drops moving at high velocity relative to the ambient fluid, and their subsequent breakup are discussed, based on previous work of Lane, Hinze, Magarvey, Taylor, Masugi, Hanson, Domick, Adams, Golitzine, and others. Further chapters are devoted to spray penetration, and to the discussion of various expressions for drop-size distributions (Rosin and Rammler, Nukiyama and Tanasawa, Log-probability function, Square-root function). Various kinds of mean diameters and their fields of application are tabulated. Several experimental sizing techniques and samplings are described. Various aspects of application of sprays in rocket motors are discussed.

Part II (pp. 77-129), "Spray combustion," deals with aspects of sprays associated with combustion and its preliminary phases, i.e., mixing of propellants, and evaporation of single drops, arrays of drops, and sprays. Previous research of Longwell and Weiss, NACA work by Ingebo and others, Froessling, Ranz and Marshall, Conkie and Savic, and others are described in detail, with formulas and graphs. Combustion of single drops in quiescent atmosphere is discussed based on the work of Godsave, Spalding, Goldsmith and Penner, Hall, Kobayasi, Graves, and others. Drop array studies of Rex, Fuhs, Penner, and Tanasawa and research on complete burners by Mayorcas, Anson, and Riviere, and others are critically examined.

This is an excellent and up-to-date survey of the present state of knowledge on the subject. It is concluded that the spray combustion process is a very complex interaction of many physical and chemical rate processes; it has not yet been fully cleared up in spite of the extensive theoretical and experimental research expended on it; design of a satisfactory combustion chamber and fuel spray system still requires trial and error methods, aided by reasonable semi-empirical correlations in terms of measurable quantities.

AMR 12-2144

G-1. Gage, J. C.

"A Controlled Fluid-Feed Atomizer." J. C. Gage (Ind. Hyg. Research Labs., Welwyn, Engl.). J. Sci. Instr. 30, 25 (1953).

CA 47-3621f

G-2. Gallily, I., and V. K. La Mer

5301. Gallily, I., and La Mer, V. K., On the behavior of liquid droplets after impinging on solid surfaces, *J. Phys. Chem.* 62, 10, 1295-1299, Oct. 1958.

Deposition of particles impinging on solid surfaces was investigated for a system composed of a two-dimensional jet of glycerol aerosol and Desicote-coated glass microscope slides inclined to it. The patterns of particles deposited in these experiments were found to change with the velocity of the jet and the radius of the aerosol, in a manner different from previous assumptions that the particle would adhere to a solid surface at its first point of contact. Present tests indicate that a certain fraction of the particles bounces off from the surface on first contact. Authors discuss criterion droplets of adhering or bouncing off of impinging droplets on the basis of previous work of Gillespie, Rideal, and Rumpf, and define the concept of "sticking probability." Experimental set-up consisted of an aerosol generator, a flow conduit terminating in a rectangular nozzle, a machined plate containing the collecting surface, and intercepting devices for sampling purposes; these elements are illustrated and described. Procedure is explained in detail; some results of cumulative distribution of distances are shown in table and in chart. A qualitative explanation of the phenomena found is offered, based on the strain of the deformed droplet and its release, the viscous drag of the air, and the Brownian motion of the particle in the stream line. An equation expressing the adhesional force is offered; the effect of electrostatic force is slight compared with the van der Waals forces of attraction.

AMR 12-5301

G-3. Ganz, S. N., and I. E. Kuznetsov

"Design of Uniform-Flow Towers with Centrifugal Atomizers." S. N. Ganz and I. E. Kuznetsov (F. E. Dzerzhinskii Chem.-Technol. Inst., Dnepropetrovsk). Izv. Vysshikh Uchebn. Zavedenii, Khim. i Khim. Tekhnol. 8(1), 151-4 (1965)

CA 63-2637e

G-4. Garner, F. H., S. R. M. Ellis, and J. A. Lacey, Trans. Inst. Chem. Engrs. 32, 222-35 (1954).

The size distribution and entrainment of droplets in a pilot plant evaporator and in a 4 inch glass evaporator have been determined from the evaporation of water and potassium nitrate solutions. Samples of the entrained droplets were collected in a two-stage cascade impactor and the entrainment was calculated from the size and total number of droplets. Entrainment was also determined by measuring the concentration of salt in the condensed vapour from the potassium nitrate solution.

It was found that 95% of the droplets entrained in the vapour space of the evaporators were below 20 microns, but because of their low mass they formed only a very small fraction of the total weight of the entrained liquid.

A study of the size distribution and entrainment of droplets from bursting bubbles has shown that droplets are formed both by the collapse of the bubble dome and by the disintegration of the jet of liquid arising from the bubble crater. The relative magnitude of these two effects depended upon the size of the bubbles. Droplets from the rupture of bubbles larger than 0·5 cm. diameter were almost entirely produced from the bubble dome. Stabilisation of the bubble by the presence of dissolved or suspended solids decreased the number of droplets produced.

Author

G-5. Garner, F. H., and V. E. Henny

"Behaviour of Sprays Under High Altitude Conditions," Fuel 32, 151 (1953)

G-6. Garner, F. H., A. H. Nissan, and G. F. Wood

Thermodynamics and Rheological Behavior of Elasto-Viscous Systems Under Stress. F. H. Garner, A. H. Nissan, and G. F. Wood. Phil. Trans., Roy. Soc. London, Vol. 243 (1950), No. 858, pp. 37–66. 30 p., 15 fig., 3 ref.

Experiments on hollow conical jets. Newtonian liquids break up when the kinetic energy of the jet exceeds a certain function of the surface energy which had stabilized the sheets. With elasto-viscous systems (non-Newtonian liquids), the kinetic energy required to break up the expanding conical sheets is much greater than this function. Construction and principles of cohesimeter and an apparatus for measuring the free energy increase with strain. Experiments confirm hypothesis that increase in free energy on straining (or stressing) the system results in local instability.

deJ I-113

G-7. Gaskins, F. H., and W. Philipott

"Breakup of Viscoelastic Jets," pp. 91-110 in "Spray Dissemination of Agents," Report of Symposium VIII, Vol. II, Conducted by U.S. Army, CWL March 4-6, 1958. SECRET

AD 304 460

G-8. Gavis, J.

10671. PROPAGATION OF TRANSVERSE WAVES ON VISCOELASTIC JETS. J.Gavis.
Industr. engng Chem., Vol. 51, No. 7, 885-6 (July, 1959).

A technique has been developed by which the relaxing tensile stress in the jet as it leaves the nozzle can be measured by wave propagation. This technique is discussed with special reference to the general problem of wave propagation in jets. It is shown that if the shear modulus of the liquid at the propagation frequency is in the range from 10^3 to 10^4 dyn/cm^2, then the propagation can be described by comparatively simple equations.

PA 62-10671

G-9. Gebhardt, H.

503. Gebhardt, H., Atomization with swirl nozzles, Parts I and II (in German), *Maschinenbautechnik* 8, 1, 33-39, Jan. 1959; 8, 2, 83-91, Feb. 1959.

This paper covers essentially the same subject as the previous paper of the author: "Atomization with swirl nozzles" [AMR 12 (1959), Rev. 4200]. The nozzles were investigated mainly as regards their suitability for the atomization of heavy fuels, i. e., diesel oil, and tar oils from hard and soft coal. Flow rate, spray angle, and fineness of atomization were measured as functions of injection pressure, nozzle dimensions, and state of the liquid. Fineness of atomization was defined by the size of the largest drops. Flow coefficient of a nozzle could be expressed as a function of the Reynolds number. Drop size was found to depend mostly on injection pressure and on the viscosity of liquid. With the aid of the found relations, data obtained with water can be transferred to other liquids. Diagrams have been developed for designing nozzles for varied operating conditions.

AMR 13-503

G-10. Gebhardt, H.

4200. Gebhardt, H., Drop sizes with swirl-nozzle atomization (in German), *Brennstoff-Wärme-Kraft* 10, 8, 361-366, Aug. 1958.

Experimental determination of drop size distribution in sprays, using swirl nozzle and heavy fuel oil, is made by exposing, for a short time, a glycerine-covered microscope slide to the spray. Droplets of 1-micron size were found at all injection pressures. Experiments were made also with direct photography with spark illumination, the light duration being about 1.5×10^{-6} sec. The largest drops were in the 50 to 1000-micron range. Author corroborates the finding of Troesch that the largest drops are characteristic for the type of atomization. The largest drop size represented as a function of atomizing pressure gives hyperbola-like curves, with the atomized liquid as parameter. Viscosity has important influence on the drop size.

The results are represented as a nondimensional expression for drop size, as a function of the Weber number expressing the characteristics of the swirl nozzle. From these data a nomogram has been constructed whereby the maximum drop size can be determined for an atomized liquid of known characteristics. Apparatus is illustrated and described, samples of spray photos are shown; calculation of characteristic quantities and construction of charts are explained.

This is a detailed investigation, giving also a background of previous researches, and the significance of the findings for practical applications.

AMR 12-4200

G-11. Gebhardt, H.

1072. Gebhardt, H., Atomization with swirl nozzles (in German), *Wiss. Zeitschr. techn. Hochsch., Dresden* 7, 2, 249-273, 1957-58. (Condensed form, *Brennstoff-Waerme-Kraft* 10, 8, 361-366, 1958).

Theoretical and experimental research on the atomization characteristics of swirl nozzles, in particular regarding their suitability for heavy oils (diesel oil, coal-tar oils). Rate of discharge, spray angle, and fineness of atomization were measured as functions of nozzle dimensions, injection pressure, and fuel characteristics. The drops were photographed using a spark-flash illumination, and the largest drops were considered as the measure of the goodness of atomization. The efflux coefficient of the nozzle was found to be a function of the Reynolds number. The results are represented in an uniform manner as functions of dimensionless ratios of nozzle dimensions. Spray angle was determined as a function of nozzle characteristics, orifice size, and viscosity of the liquid. Drop size depends mostly on injection pressure and viscosity of the liquid. By means of the found relationship it is possible to apply the results with water to other liquids. Diagrams are given whereby swirl nozzles can be designed for a great variety of operational conditions. Work of previous investigators is discussed. Experimental setup is illustrated and procedure described. Sample photographs of drops, and distribution of spray in a cross section are given. Nomograms for drop size were constructed.

AMR 12-1072

G-12. Geist, J. M.

"An Electronic Spray Analyzer for Electrically Conducting Particles." Jacob Myer Geist (Univ. of Michigan, Ann Arbor). Univ. Microfilms (Ann Arbor, Mich.), Pub. No. 3498, 81 pp. (microfilm $1.01, paper enlargements $8.10); Dissertation Abstracts (formerly Microfilm Abstracts) 12, 167 (1952); cf. C.A. 45, 7828a.

CA 46-6865d

G-13. Geist, J. M., J. L. York, and G. G. Brown

9077. Electronic spray analyzer for electrically conducting particles. J. M. Geist, J. L. York and G. G. Brown. *Industr. Engng Chem.*, 43, 1371-7 (*June*, 1951).

Analyses of sprays and other suspensions frequently involve sampling with microscope, slides, cells, or other relatively large devices, followed by tedious counting procedures. This paper presents some calculations to emphasize the advantage of small samplers and describes preliminary work in the development of an electronic analyser which utilizes a small sampler to measure and to count the particles. Metal spheres, with diameters from 500 to 6 340 microns, and drops of water, alcohol and acetone, with diameters from 2 500 to 4 500 microns, provide data to show that the electrical pulses created upon interception of the particles by the probe wire are proportional to the 1·6 power of the particle diameter. The effects of probe geometry and potential are shown, and the underlying mechanism is discussed. With further development of the geometry of the probe, the electronic spray analyser may offer an extremely rapid method for determining the drop size and size distribution in the spray of an operating nozzle, with a minimum sampling error.

PA 54-9077

G-14. Gelalles, A. G.

GELALLES 1930

Some Effects of Air and Fuel Oil Temperatures on Spray Penetration and Dispersion. A. G. Gelalles. NACA Tech. Note 338 (1930) 10 p., 6 fig., 4 ref.

Results of investigation on appearance, penetration and dispersion of oil sprays injected into a chamber with mica windows containing heated air at atmospheric pressure. Photographs of fuel sprays from a 0.004 inch orifice plain nozzle, injected at 4000 and 8000 psi into air at atmospheric density. For each injection pressure one photograph is shown with the fuel and air at room temperature, and another with fuel and air temperatures of 110° and 1100°F. Curves of spray-tip penetration against time, derived from published photographs.

deJ I-115

G-15. Gel´perin, N. I., and S. A. Vil´nits

5007. Gel'perin, N. I., and Vil'nits, S. A., Emission of liquids from deposits and openings of small diameter (in Russian), *Trudi Mosk. in-ta ton-Kol Khim. tekhnologii* no. 5, 27–36, 1955; *Ref. Zh. Mekh.* no. 1, 1957, Rev. 442.

A description is furnished of the apparatus and the results of experiments on the determination of the coefficient of discharge, when eight types of liquids pass from cylindrical deposits with diameters $0.445 \leq d \leq 1.5$ mm and openings $0.25 \leq d \leq 1.3$ mm. The work was carried out under conditions applicable to the extraction of substances by means of solvents from liquid solutions in plant in the chemical industry. Experimental dependencies in the criterion aspect (dependence on Reynolds number and the complex appearing as the relation of the viscosity forces and the forces of capillarity) are given for determining the coefficient of discharge when the flow is in the droplet or stream form, and the boundaries are determined between these forms.

AMR 11-5007

G-16. Gershenzon, E. L., and O. K. Eknadiosyants

4492. Gershenzon, E. L., and Eknadiosyants, O. K., The nature of liquid atomization in an ultrasonic fountain, *Soviet Physics-Acoustics* **10**, 2, 127–132, Oct./Dec. 1964. (Translation of *Akust. Zh.* **10**, 2, 156–162, Apr./June 1964 by American Institute of Physics, Inc., New York, N. Y.)

The importance of the value of the saturated vapor pressure, p, of a liquid for its atomization by ultrasonics of constant intensity and at a frequency of 2×10^6 c/s was demonstrated on 16 liquids of widely varying vapor pressures at 20°C. The gravimetrically determined atomization capacity, A (i.e., the grams of aerosol formed per sec), was found to be connected with a parameter $\beta = p/\eta\sigma$ (where η = dynamic viscosity of the liquid and σ = surface tension of the liquid). Pairs of liquids of similar η- and σ-values were selected and of different p-values. For these pairs the ratios β/β_1 and A^1/A_1^1 were calculated. It then became apparent that for all the liquids but water (whose surface tension is much higher than those of the other 15 liquids) the ratio $\dfrac{A^1/A_1^1}{\beta/\beta_1}$ was either about 0.5 or 1. This was regarded as support for the cavitation mechanism of the ultrasonic formation of aerosols. Similar regularities were found for sonoluminescence, where the flux, L, varied with σ^3, so that a straightline relationship emerged between L and σ^3/p, again with water lying off this straight line.

AMR 18-4492

G-17. Gessner, H.

Eine einfache Methode zur Bestimmung der Tropfengrößen von Zerteilerdüsen (A simple method for determination of the drop sizes of atomizing nozzles). H. Gessner. Schweizer Archiv (Switzerland) Vol. 1 (1935), pp. 199–204, 7 fig.

Method for collecting drops of colored liquid, atomized 27 ft. above a filter paper, strips of which are successively exposed for known time intervals to receive the falling drops. By means of Stokes' law, modified for the largest and the smallest drops according to Oseen and Cunningham, the drop sizes collected on each strip are calculated. Description of procedure, sample results, presentation of results, and assessment of experimental errors, applied to spray with drops from 130 to 1250 microns having terminal velocities of 28 cm./sec. to 164 cm./sec. A completely evaluated example is given.

deJ I-117

G-18. Giffen, E.

1309. Giffen, E., Atomization of fuel sprays, *Engineering* 174, 4510, 6–10, July 1952.

Paper describes experiments on swirl atomiser sprays. Intermittent and continuous sprays were investigated at discharge velocities less than 80 ft/sec. Intermittent spray samples were obtained by impingement on magnesium oxide coated slides. In continuous tests, dye was added to liquid and spray was discharged horizontally over a series of troughs containing undyed liquid. Dye color intensity gave spray volume per trough. Comparison with impingement samples gave spray characteristics for each trough.

Results: Effect of increase in discharge velocity was to decrease mean droplet size and to increase proportion of small drops. Drop size decreased with increasing distance from nozzle—as would be expected, this effect was most pronounced at higher velocities. Viscosity and surface-tension tests were conducted using safety fuel, light lube oil, and water (viscosity range 15-fold, surface tension range 3-fold). Increase in viscosity caused not only an increase in mean drop size, but also a large increase in size of largest drops—this effect was most noticeable at low velocities. By comparison, effect of surface tension was barely noticeable.

AMR 6-1309

G-19. Giffen, E., and T. A. J. Lamb

The Effect of Air Density on Spray Atomization. E. Giffen and T. A. J. Lamb (Queen Mary College, London). The Motor Industry Research Association (MIRA), Rep. No. 1953/5. 14 p., 16 fig., 3 ref.

Sprays were discharged from a single-hole Diesel atomizer fitted into the top of a pressure chamber and samples were collected on slides coated with magnesium oxide, for counting the drops and measuring drop diameters. The slides were placed inside the chamber at a sufficient distance from the atomizer to ensure that complete atomization had been attained before the spray droplets were collected. By restricting the time-duration of spraying, overlapping of the droplets falling on the slides was avoided. Apparatus was designed to produce a very short injection at a known injection pressure; it is illustrated schematically.

Tests were made at 0, 50, 100, 200, 400, and 600 psi air pressure. Main drop size and non-uniformity factor were calculated for each test; data are presented as drop-size frequency curves. Fineness and uniformity of a liquid spray improve with increase of air density, but the rate of improvement- which consists mainly in the decrease in the size and number of the big drops in the spray, diminishes at higher air densities. With increasing air density the minimum size of drop in the spray is largely unaffected, the maximum size is reduced considerably, and variation in mean drop size across the spray cross section is reduced.

deJ I-120

G-20. Giffen, E., and B. S. Massey

'GIFFEN and MASSEY 1951

Some Experiments on Spray Atomization with Swirl Atomizers. E. Giffen and B. S. Massey (Queen Mary College, London). Motor Industries Research Association Rept. No. 1951/4 (1951). 11 p., 8 fig., 5 ref.

Investigation on atomization of sprays from two types of swirl atomizers with safety fuel, a light lubricating oil, and water. Results expressed as number-frequency curves and also in terms of the Sauter Mean Diameter show the importance of the tangential component of velocity in giving finer atomization. Effect of viscosity, and surface tension of liquid on the degree of atomization. Viscosity has a large but indirect influence on the degree of atomization. Surface tension has little effect on atomization from a centrifugal atomizer. Within the range of variables covered in the experiments, the data point to the existence of a minimum drop diameter of about 10 microns for these sprays discharged into the atmosphere. With continuous sprays the penetration became long, necessitating use of long collecting trays. Therefore a rotating disc with a cut-out window was placed in front of the nozzle whereby the spray duration was reduced.

deJ I-119

G-21. Giffen, E., and B. S. Massey

Some Observations on Flow in Spray Nozzles. E. Giffen and B. S. Massey (Queen Mary College, London). MIRA, Rept. No. 1950/5 (1950). 16 p., 18 fig., 4 ref.

Investigation with two different swirl-type, and one spring-loaded poppet valve spray nozzles, using liquids of different viscosities ranging between 2 and 50 centistokes, and surface tensions ranging between 24 to 70 dynes per cm., at injection pressures up to 300 psi. (The same nozzles were used in experiments described in GIFFEN and MURASZEW 1948.) Apparatus for producing sprays for measuring spray angle and amount of discharge are described and illustrated. Measurements made on coefficient of discharge, air core diameter, and spray cone angle.From these measurements, relationships between axial, radial, and tangential velocity components of the sprays were calculated. Curves show effect of viscosity, and of orifice length-to-diameter ratio, on cones angles of swirl nozzles.

deJ I-119

G-22. Giffen, E., and A. Muraszew

2642. Giffen, E., and Muraszew, A., The atomisation of liquid fuels, New York, John Wiley & Sons, Inc., 1953, x + 246 pp. $6.

Whenever liquid fuel is used as a source of heat (as in a furnace) or as a source of mechanical energy (as in internal-combustion engines, gas turbines, and jet engines), the fuel must first be atomized, i.e., broken up into small droplets, before combustion can take place. On the characteristics of atomization, i.e., on the degree of fineness and evenness of the spray, and on its distribution in space and time, depends to a large degree the efficiency of combustion, hence the economy of fuel utilization.

A great deal of research work has been expended and much still remains to be done in order to clarify the physical phenomenon of atomization, to assess the influence of the numerous variables of the fuel and the surrounding gas or air on the properties of the spray, to measure the significant properties, and thereby to give the practical problems of spray production a sound theoretical foundation. This is a difficult task because spray science comprises a number of disciplines, such as mathematics, physics, hydro- and aerodynamics, and mechanical engineering.

The book under review deals with the problems and methods of theoretical and experimental investigation of sprays. The authors, themselves meritorious contributors to this branch of science, have produced an authoritative and comprehensive treatise. There are ten chapters—about 70 sections and subsections—arranged in a logical sequence. Listing these will indicate the scope of the book:

Mechanism of disintegration of liquid jets; motion of small liquid drops in air; spray formation and penetration, energy of atomization and a survey of spray formation theories. Spray characteristics such as cone angle, dispersion, size, and uniformity of droplets. Effect of atomizer design on flow in atomizer, spray penetration, and cone angle. Theory of the swirl atomizer, air core, and cone angle. Dimensional analysis applied to the correlation of atomization data. Effect of physical properties of the liquid on spray dispersion, cone angle, velocity, and penetration. Effect of the properties of the gaseous medium on the spray properties. Effect of the injection pressure on spray penetration, cone angle, and droplet size. Formation and development of intermittent and continuous sprays; variation of pressure and velocity; progressive development of atomization. Experimental methods for the assessment of fuel-spray characteristics, of velocity, penetration, cone angle, structure, dispersion, droplet size; use of substitute liquids for droplet measurement.

A list of about 100 references is included. This is a well-balanced treatise, written in a lucid style, an excellent introduction and sound foundation for those concerned with atomized fuels.

AMR 7-2442

G-23. Giffen, E., and A. Muraszew

Fuel Injection in Internal Combustion Engines; Atomization of Low-Pressure Fuel Sprays. E. Giffen and A. Muraszew. MIRA (Engl.) Rept. No. 1948/5 (1948). 57 p., 73 fig., 3 ref.

For three nozzle types (open centrifugal, poppet-valve, and swirl-chamber) the formation and development of the spray in time and space, the effect of pressure oscillations at the nozzle on the process of atomization by comparing intermittent and continuous injections, and the drop size distribution were investigated. Description of the experimental apparatus including a rotating "window disc" for examining a pre-determined phase of an intermittent spray. The following characteristics of the spray are discussed and documented with test results: penetration, size distribution, dispersion, spray development, fineness and uniformity, and spray formation. Mechanism of atomization is considered in relation to the results obtained. Conclusions are drawn regarding the importance of centrifugal motion of the fuel on the fineness of the spray, the process of formation of drops of various sizes, and the causes of non-uniformity in the spray. Finds that the Rosin-Rammler relationship does not fit well the fuel sprays.

deJ I-118

G-24. Giffen, E., and A. Muraszew

Fuel Injection in Internal Combustion Engines; the Measurement of Atomization in Fuel Sprays. E. Giffen and A. Muraszew (Queen Mary College, London). MIRA (Engl.) Rep. 1948/4 (1948). 19 p., 17 fig., 13 ref.

From an intermittent fuel spray, using a centrifugal nozzle, samples of drops were collected on glass slides coated with magnesium oxide, at different periods during injection and at different distances from the nozzle, and the samples were analyzed for drop size distribution. The impressions on the coated slides are not the same size as the drops, and a calibration curve was used. From the distribution curves the Sauter Mean Diameter was obtained. In another method dyed fuel was used and the volumes of drops falling at different distances from the nozzle were measured colorimetrically. Calculated volume of drops in the spray was compared with the volume found by collecting and weighing a number of samples discharged under the same conditions; an agreement, within 15% by volume, was found. Results showed fair agreement with the molten wax method.

deJ I-118

G-25. Giffen, E., and M. C. Neale

Effect of Gas Viscosity on Spray Atomization. E. Giffen and M. C. Neale (Queen Mary College, London). The Motor Industry Research Association (MIRA), Rep. No. 1954/4, 7 p., 4 fig., 3 ref.

Experiments were made with a single-hole atomizer discharging safety fuel into a vessel containing one of a series of gases chosen to give a range of gas viscosity, namely: hydrogen, carbon dioxide, air and argon, having viscosities ranging from 89×10^{-6} to 222×10^{-6} poises. In one series of experiments the pressures of the gases were chosen so that the densities were all 0.038 lb/cu. ft. In each experiment a small quantity of liquid was injected under such conditions that the gas viscosity was the only variable. A sample of the spray was collected on glass slides coated with magnesium oxide, and droplet sizes were estimated. Results are shown as drop-size frequency curves and also in terms of Sauter Mean Diameter.

Viscosity of the gas into which a spray is discharged had little effect on atomization of spray if conditions are such that air resistance plays only a small part in the process of disruption; such conditions exist when the jet has a high discharge velocity, or when it has a high radial velocity component, or when the viscosity of the liquid is small.

Increasing the gas viscosity decreased the mean drop size, reducing the number of large drops and increasing the number of small drops. For the plain atomiser used, the drop size distribution in the spray cross section became more uniform and the spray dispersion improved as the gas viscosity was increased.

deJ I-120

G-26. Gignoux, D., H. F. Anton, and J. J. Shea

N65-15876*# Cosmic, Inc., Washington, D.C.
DEVELOPMENT OF A CHARGED COLLOID SOURCE FOR ELECTROSTATIC PROPULSION Report No. 82

D. Gignoux, H. F. Anton, and J. J. Shea Oct. 1964 78 p refs
(Contract NAS3-4106)
(NASA-CR-54178) OTS: HC $3.00/MF $0.75

A large number of tests were performed with a rotating nozzle source of induction-charged colloid. The geometry was improved, resulting in an increase of the charge-to-mass ratio by one order of magnitude with respect to a previous program. Analytically, the ideal propellant was shown to have high viscosity, low density, low surface tension, low vapor pressure, and high conductivity. The experimental values of the system parameters agreed conclusively with those predicted analytically. The search for a better propellant disclosed several promising avenues. Beam currents up to 1.5 milliamperes were obtained. The system has very promising application to high-efficiency electrostatic thrustors.

N65-15876, 06-28

G-27. Gillis, J., and B. Kaufman

4069. Gillis, J., and Kaufman, B., The stability of a rotating viscous jet, *Quart. Appl. Math.* 19, 4, 301-308, Jan. 1962.

This paper is concerned with the stability of a column of homogeneous viscous fluid rotating as a solid body. It is shown that a necessary and sufficient condition for stability for perturbations of azimuthal wave numbers s and axial wave number ζ is

$$T \gtrless \rho a^3 \omega^2 (a^2\zeta^2 + s^2 - 1)^{-1}$$

where T is the surface tension, ρ the fluid density, a the column radius and ω the angular velocity. This condition applies provided the right hand side of this relation is positive; if it is negative the motion is always unstable. It is demonstrated that this general result includes special cases previously considered by Rayleigh and Hocking.

AMR 15-4069

G-28. Gillis, J., and K. S. Suh

336 Stability of a **Rotating Liquid Column.**— The **stability** of a rotating cylindrical column of liquid with a concentric solid core is discussed. The critical value of the surface tension is determined for the case of a viscous liquid while, for a nonviscous liquid, the problem is solved for axisymmetric and plane perturbations. The physical significance of the results is also discussed. — J. Gillis and K. S. Suh. *Physics of Fluids*, v. 5, Oct. 1962, p. 1149-1155.

EM1 12-336

G-29. Gilman, S.

A Photographic Method of Determining the Size Distribution of Small Particles. S. Gilman. M. S. Thesis, Univ. of Pittsburgh, 1942. 16 p., 4 fig., 7 graphs, 7 ref.

Shadowgraphs of water-spray drops by spark illumination and a view camera, giving images of about natural size. Numerical calculation of the spark circuit and of the optical system, also some results on air-atomizing (Spraying Systems Co.) and liquid spray (Spray Engineering Co.) nozzles and fly ash. Sample photographs at 32× magnification. Determines specific surface and several average diameters. Suggestions for improvements.

deJ I-122

G-30. Glahn, U. H. von, T. F. Gelder, and W. H. Smyers

2928. von Glahn, U. H., Gelder, T. F., and Smyers, W. H., Jr., A dye-tracer technique for experimentally obtaining impingement characteristics of arbitrary bodies and a method for determining droplet size distribution, *NACA TN* 3338, 73 pp., Mar. 1955.

The experimental details are given for applying a rather difficult technique. Dyed water is collected on blotting paper and strips are analyzed colorimetrically. E. Brun of ONERA has described similar methods using photographic paper in a spray of developer solution or methylene blue on a glossy paper. Authors show surprisingly small deviations from analytical trajectory solutions in view of difficulty of keeping uniform spray, low tunnel turbulence, and nonhomogeneous clouds.

AMR 8-2928

G-31. Glendenning, E. B. et al

Atomization of Oil by Small Pressure Atomizing Nozzles. E. B. Glendenning, A. R. Elack, L. H. Ventres, and W. A. Sullivan. Trans. ASME, Vol. 61 (1939), pp. 373–381, 12 fig.

Importance of atomization, carburetion, and oil characteristics for efficient combustion; effect of pump pressure, oil viscosity, variation in oil temperature, and nozzle design on the rate of efflux and spray characteristics. A study of hollow-cone and center spray nozzles with relation to oil viscosity; aerodynamic design of the oil burner; combustion efficiency. Nozzles had a capacity of 1 to 3 gal./hr., as used in domestic oil burners; atomizing pressure 50 to 200 psi. Viscosity was found to be the main influencing factor on nozzle capacity, angle of spray, degree of atomization, characteristics of flame, and efficiency of combustion.

deJ I-123

G-32. Glonti, G. A.

9289. ON THE THEORY OF THE STABILITY OF LIQUIDS JETS IN AN ELECTRIC FIELD. G.A.Glonti.
Zh. eksper. teor. Fiz., Vol. 34, No. 5, 1329-30 (May, 1958).
In Russian. English summary: PB 141052T-2, obtainable from Office of Technical Services, U.S. Dept. of Commerce, Washington, D.C., U.S.A.

The electrostatic field equation is combined with the general hydrodynamic equation for a viscous fluid, as is done in magneto-hydrodynamics, to study the criteria for stability of a cylindrical jet of liquid dielectric in an electrostatic field. The effects of viscosity and direction of the field are examined as well as that of jet radius. Conditions for equilibrium at the surface are given.

PA 62-9289

G-33. Golitzine, N.

3663. Golitzine, N., The spraying of liquids, *Nat. Res. Counc. Canad., Div. mech. Engng. Quart. Bull.* 14 pp. + 10 figs., Jan.-Mar. 1954.

Spraying of liquids enters into many fields of science and industry, as well as into medicine, agriculture, war, meteorology, and everyday life. Paper surveys application of sprays. Types of sprayers include straight jet, swirl nozzles, pneumatic spray nozzles, rotating sprayers, combinations of sprayer types. Spray characteristics are velocity, shape, penetration, rate of flow, distribution of droplet size. Methods used to study the previously listed characteristics include photography, sampling, their difficulties and tricks used. Choice of sprayers for a given purpose is indicated. Reproducibility of sprays, as in successive injections into a diesel engine, is mentioned.

This is a good orientative article, giving a bird's-eye view of spray science and technology, which provides an instructive introduction for deeper and more detailed studies.

AMR 9-3663

G-34. Golitzine, N.

Method for Measuring the Size of Water Droplets in Clouds, Fogs, and Sprays. N. Golitzine. Nat'l Aeron. Establ. (Canada), Note No. 6 (1951), 13 p., 22 fig., 9 ref. Also published as Rept. ME-177, Div. of Mech. Engg., Nat'l Res. Council, Canada. 1950.

Method consists in collecting water drops on an oil covered glass slide, then immediately taking a photomicrograph of the sample. A special oil is used which retards the evaporation of the droplets long enough to have a photomicrograph taken. The drops maintain a nearly spherical shape in the oil; their diameter is measured. Range of sizes measured: 5 to 250 microns. Samples were taken at various airplane speeds, on slides of various sizes, and at different durations of exposure, and the influence of these factors on the median drop diameter investigated. Samples were taken of clouds, fogs, rains, steam cloud in a room, of sprays produced by pneumatic and swirl nozzles.

deJ I-125

G-35. Golitzine, N., C. R. Sharp, and L. G. Badham

"Spray Nozzles for the Simulation of Cloud Conditions in Icing Tests of Jet Engines," Nat. Aero. Est. Report #14, 1951, 17 p.

G-36. Golovin, A. M.

"The Theory of the Vibration and Breakdown of Droplets in a Gas Stream in the Presence of Rotational Motion Inside the Droplets. I."
A. M. Golovin (Akademiia Nauk SSSR, Institut Elektrokhimii, Moscow, USSR).
(Akademiia Nauk SSSR, Izvestiia, Seriia Geofizicheskaia, July 1964, p. 1084-1092.)
Academy of Sciences, USSR, Bulletin Geophysics Series, July 1964, p. 658-662. 16 refs. Translation.

A65-12157, 03-20

G-37. Golovkov, L. G.

"Distribution of Droplets with Respect to Size in the Pulverization of Liquids by Swirl Injectors [Raspredelenie Kapel' Po Razmeram Pri Raspylivanii Zhidkostei Tsentrobezhnymi Forsunkami].
L. G. Golovkov.
Inzhenerno-Fizicheskii Zhurnal, vol. 7, Nov. 1964, p. 55-61. 8 refs. In Russian.

Presentation of additional proof for the validity of the assumptions used by Tresh in the derivation of his density distribution function for droplets (with respect to size). A technique for determining the parameter β in this function is proposed. The numerical value of this parameter for swirl injectors is found to be $\beta = 0.19$.

A65-12639, 03-33

G-38. Gontar, P. I.

"Effect of Water Pressure on Size Distribution of Water Drops Produced with an Atomizer." P. I. Gontar. Trudy Novocherkasskogo Politekh. Inst. 73, Raboty Kafedry Fiz. 97-100 (1959).

CA 55-26569a

G-39. Goodger, E. M.

"Fuel Spray Investigations at Cranfield." E. M. Goodger (Coll. Aeronautics, Cranfield, Engl.). Petroleum (London) 19, 387-92 (1956).

CA 51-3126b

G-40. Gorbatshev, S. V., and W. M. Nikiforowa

Über die obere Stabilitätsgrenze von Tropfen bei ihrem Zusammenprall (Upper stability limit of colliding drops). S. W. Gorbatschew and W. M. Nikoforowa (Inst. for Experimental Hydrology and Meteorology, Moskow). Kolloid-Z., Vol. 73, No. 1 (Oct.1935), pp. 14–20, 5 fig., 9 tabl., 1 ref.

In meteorology, in the formation of larger drops by coalescence of smaller drops in rain, and conversely, in the breaking up of larger drops into smaller ones, it is important to determine the upper and lower speed limits of collision within which coalescence can occur. This investigation deals with the upper speed limit.

In rain the large rain drops are formed by the coalescence of small fog droplets when the latter collide with each other. The speed of collision must be within certain limits (depending also on droplet size and other factors); if the speed of collision is too low the colliding droplets will rebound after impact; if the speed of collision is too high the colliding droplets will break up into still smaller droplets. Present investigation examines the upper speed limit, i.e., below which coalescence can occur. A droplet was attached to a glass filament; another droplet attached to a glass filament was fastened to the end of a pendulum the velocity of which could be finely regulated by varying the amplitude. The collision of droplets was observed by a microscope. Another method employed a small sled to which a varying velocity could be imparted. Both methods yielded similar quantitative results. It was found that within 0.1 to 1.5 m./sec. velocity coalescence of drops could occur; decreasing the drop size increased the upper speed limit; surface-active agents displaced somewhat the limiting speeds.

deJ I-127

G-41. Gordon, G. D.

3736. Gordon, G. D., Mechanism and speed of breakup of drops, *J. Appl. Phys.* **30, 11, 1759-1761, Nov. 1959.**

Paper presents mathematical analysis of the break-up of liquid droplets in an air stream. Analysis provides an understanding of the variables affecting secondary atomization, i.e., it is directly applicable to case where acceleration of the drop is steady and uniform, in which case the drop flattens, becomes bowl-shaped, inflates like a parachute and finally bursts (see W. R. Lane, ***Indust. Engng. Chem.*** **43, 1312-1317, 1951). Author assumes a simplified model in which he estimates the forces acting when a cylindrical plug is extruded from a drop. Resulting equations can be shown to relate critical size and break-up time to the dimensionless Weber ($d\rho_g V^2/\sigma$) and viscosity ($\mu/(\rho_d \nu d)^{1/2}$) groups. Although a number of broad assumptions are made in deriving equations, the predicted results show agreement within a factor of two with available experimental data. Results corroborate Lane's experimental observations as to the effect of surface tension and viscosity on critical size and break-up time.**

AMR 13-3736

G-42. Gordon, M. G.

"Factors Affecting Atomization of Liquids with Cold Gas," pp. 117-142 in "Spray Dissemination of Agents," Report of Symposium VIII, Vol. II, Conducted by U.S. Army, CWL March 4-6, 1958. SECRET

AD 304 460

G-43. Gordon, M. G.

AD-319 841 Div. 3/7
(3 Nov 60)

Army Chemical Research and Development Labs., Center, Md.
HOT-GAS AEROSOLIZATION OF LIQUIDS OF LOW VOLATILITY (U), by Malcolm G. Gordon. Sep 60, 49p. incl. illus. tables, 26 refs. (Rept. no. CRDLR 3030) Confidential report

Descriptors: Aerosols*; Production; Liquids; Atomization*; Vaporization; Fluid flow; Gas flow; Temperature; Aerosol generators.

TAB U61-1-1

G-44. Gordon, M. G.

Cold Gas Atomization of Low Volatility Liquids. Malcolm G. Gordon (Army Chem. Center, Md.). Rep. CWLR-2333; Jan. 1960, 30 p., 8 ref.

Bis (2-ethylhexyl)hydrogen phosphite was atomized by compressed air with a device similar to a multicompartment thermal generator, and equipped with various nozzles. The aerosols produced were characterized by several sampling techniques. Data obtained were compared to Nukiyama-Tanasawa equation; application of cold-gas technique to a practical device was considered. Conclusions: (1) for most of the nozzle designs the aerosol produced by the compressed-air laboratory device can be characterized by the Nukiyama-Tanasawa relation; (2) parameter most affecting the atomization process is the volume ratio: liquid to gas; (3) the four sampling techniques examined showed various degrees of correlation to each other and to the value predicted by the Nukiyama-Tanasawa function; (4) cold-gas atomization is not practicable for chemical munition because of low liquid capacity.

deJ II-192

G-45. Goren, S. L., and J. Gavis

6837 TRANSVERSE WAVE MOTION ON A THIN CAPILLARY JET OF A VISCOELASTIC LIQUID.
S.L.Goren and J.Gavis.
Phys. of Fluids (USA), Vol. 4, No. 5, 575-9 (May, 1961).

The equation for transverse wave propagation on a thin capillary jet of a viscoelastic fluid in which a spatially varying tensile stress is known to exist is developed. A method of solution is developed for the special case of greatest interest, $T_0 \rho u_i^2 \ll 1$, where ρ is the fluid density, and u_i and T_0 the average ejection velocity and tensile stress at the nozzle. Although this will allow solution for any form of T variation the solutions will not, in general, be obtainable in analytic form but may be obtained by use of an analogue computer, for example. A form in which T decays exponentially to a constant value is selected for illustration of an analytic solution, and the features of the resulting wave pattern are discussed.

PA 64-6837

G-46. Graf, P. E.

"Breakup of Small Liquid Volumes by Electrical Charging." API Res. Conf. on Distillate Fuel Combustion Conference Paper CP-62-4. June 19-20, 1962, Chicago.

Atomization of organic liquids can be produced by electrical charging. This results from the pressure developed by the mutual repulsion of surface charges. When the electrical pressure exceeds a critical value determined by the drop's surface tension and radius, the surface becomes unstable and a liquid jet is ejected. A dispersion of fine droplets is obtained as the jet breaks up.

Electrical pressure, P_e, can be calculated from

$$P_e = F \frac{V^2}{8\pi r^2}$$

where V is the applied voltage, r is the drop radius, and F is a charging factor. The charging factor, which represents the fraction of the applied potential attained on the drop surface, decreases with increasing liquid conductivity and increasing electrode spacing. The electrical pressure is largely independent of the charging electrode's configuration and polarity and of the liquid's dielectric constant. A charging mechanism is discussed in terms of ion migration in an electrical field. The rate of charging determines the continuity of jet ejection and the quality of atomization. High charging rates are obtained with (1) high liquid conductivity, (2) large charging electrode surface, (3) high potential gradient.

Author

G-47. Green, H. L.

Atomization of Liquids. H. L. Green (Chem. Defence Exper. Establ., Porton Down, Wilts. Engl.) Chapter in HERMANS 1953, pp. 299–322, 11 fig., 2 tabl., 43 equ.

Treats: Flow of swirling liquid through an orifice (flow conditions in a swirl atomizer, Taylor's boundary-layer theory, application of Pohlhausen's method, calculation of thickness of boundary layer, sizes of droplets produced by a swirl atomizer). Shattering of a jet of liquid in an air blast (mechanism of disruption, breakup of drops, surface disturbance, experimental investigations). Atomization from a rotating surface (mechanism of dispersion, formation of droplets of uniform size, theoretical derivation of drop size, variation of droplet size from spinning top). Drop-size distribution of atomized liquids (determination of drop size, distribution functions, Nukiyama and Tanasawa equation, logarithmic probability law).

deJ II-194

G-48. Green, H. L.

"Some Aspects of Fluid Flow. Ch V: Problems in the Atomization of Liquids," The Institute of Physics Edward Arnold Co., London, 1951.

G-49. Green, H. L.

The Effect of Non-Uniformity and Particle Shape on "Average Particle Size." Henry Green (Res. Lab., New Jersey Zinc Co., Palmerton, Pa.). Jl. Franklin Inst., Vol. 204, Dec. 1927, pp. 713–729, 4 tabl., 3 ref.

Gives rigorous mathematical definitions to concepts: "average diameter", "non-uniform particulate substance", in terms of number, linear dimension, surface area. Discusses: effect of non-uniformity on average particle size; mixture of non-uniform materials; effect of shape on average particle size.

deJ II-194

G-50. Green, H. L., and W. R. Lane

Particulate Clouds: Dusts, Smokes, and Mists. H. L. Green and W. R. Lane (Chem. Defence Exper. Establ., Porton Down, nr. Salisbury, Wiltshire, Engl.). D. VanNostrand Co., Inc., Princeton, N. J. 1957. XIX + 436 p., about 140 fig., numerous tabl., about 1000 ref. (no titl.).

Treats the subject, in Part I, pp. 3–277, from aspect of physics and physical chemistry, and in Part II, pp. 281–410, from industrial and environmental aspects. Chapter headings and their main contents are: Introduction (definitions and properties of dusts, smokes and mists); Production of particulate clouds (condensation, nucleation, polydisperse aerosols, mixing gas streams, electric arcs, photolysis, atomization by mechanical and ultrasonic methods, formation of dusts); Physical characteristics (structural features, rate of fall, terminal velocity, Brownian motion, electrification, evaporation of single drops and of clouds); Optical properties (Rayleigh's law of scattering, Mie's theory, geometrical and physical optics, estimation of particle size: from intensity of scattered light, spectral colors, coronae); Coagulation (equations for monodisperse aerosols, factors: mass concentration and particle size, polydispersity, differential settling, particle shape, effect of foreign vapors and of Van der Waals forces, stirred aerosols, electrical charge, acoustic field); Deposition and filtration (settling, impaction of particles, collection efficiency of cylinders and spheres, deposition in thermal gradient, photophoresis, thermal forces, deposition in electric field, filtration: qualitative, theoretical, effect of inertia, electrical filters); Sampling and estimation (size parameters, counting and sizing: by optical and electron microscopy. X-ray diffraction, ultra microscope, electrostatic particle counter, particle size: by rate of fall of individuals, and of cloud, conifuge, automatic assessment, measurement of surface area, collection for weighing, collection of volatiles, electrostatic and thermal precipitation); Diffusion in the atmosphere (eddy diffusion, turbulence, dust from chimney stacks, coagulation in a windborne cloud); Collection (gravitational settling, inertial separation, cyclones, washing and wet scrubbing, electrostatic precipitation, air filters); Health hazards (classification, pneumoconiosis, size frequency in dusts, inhalation, individual protection, filters, respirators, radioactive and microbiological aerosols, airborne infection, tobacco smoke); Atmospheric pollution (smoke, smog, chemical contaminants, suspended impurities, smoke filters and recorders, optical measurement, droplet size in smogs, environmental studies); Aerosols in nature (cloud, mist, fog, haze, condensation nuclei, droplet growth, ice particles, artificial nucleation, dissipation of fog, ice on aircraft, form of accretion, visibility, visual range by day and night). Uses of particulate clouds (in industry, for therapy, screening and signal smokes, in agriculture and pest control).

deJ II-195

G-51. Greenough, G. K.

Wax-atomizer for producing spherical dust particles. G. K. Greenough. Jl. Sci. Instr., London, Vol. 37, Apr. 1960, pp. 123–124, 3 fig.

Illustrates and describes an airblast atomizer which produces spherical wax particles suitable for investigating aerodynamic behavior of dust. The wax is melted in a closed metal container, and ejected from a nozzle under low pressure; the nozzle is surrounded by an annular nozzle for pressure air which atomizes the wax stream. Shows typical microgram, and size distribution, obtained with wax pressure of 6 cm. Hg, and air pressure of 10 cm. Hg. Particle spectrum ranges from 0.5 to 20 micron diam., and concentration up to 24,500 particles per cc.

deJ II-195

G-52. Gretzinger, J.

"An Investigation of Pneumatic Atomizers," Ph.D Thesis, University of Wisconsin, 1956.

G-53. Gretzinger, J., and W. R. Marshall

"Characteristics of Pneumatic Atomization," A.I.Ch.E. Journal 7, no. 2, 312-8 (June 1961).

G-54. Griffith, L.

"A Theory of the Size Distribution of Particles in a Comminuted System," Canad. J. Res. 21, 57-64 (1943).

G-55. Grosvenor, G.

933. **Grosvenor, G., Atomization of liquid fuels by high pressure natural gas,** *Combustion* 27, 4, 51-53, Oct. 1955.

To improve flame effectiveness in open-hearth steel making, studies were made of flame patterns of oil and gas burners and the influence exerted upon them by the inner cone with particular emphasis on the role of the atomizing agents—air, steam, and natural gas—the last of which produced particularly good results.

AMR 9-933

G-56. Gucker, F. T., and G. J. Doyle

13450 The Amplitude of Vibration of Aerosol Droplets in a Sonic Field. Frank T. Gucker and George J. Doyle. *Journal of Physical Chemistry*, v. 60, July 1956, p. 989-996.
A determination of the amplitudes of vibration of non-volatile plasticizers in a standing sonic field of 4.85 kc. per sec.

BM1 5-13450

G-57. Gunn, R.

"Collision Characteristics of Freely Falling Water Drops," Science 150, No. 3697, 695-701 (November 5, 1965).

G-58. Gurevich, M. I.

4656. **Gurevich, M. I., On the instability of certain jet flows with free surfaces,** *Soviet Phys.-Doklady* 4, 1, 54-56, Aug. 1959. (Translation of *Doklady Akad. Nauk SSSR (N.S.)* 124, 5, 998-1000, Jan./Feb. 1959 by Amer. Inst. Phys., Inc., New York, N. Y.)

Potential flow of uniform liquid with free surface in absence of gravity, with and without surface tension, vacuum above, is considered to see if it is unstable. Particular interest lies in the conclusion that disturbances may grow exponentially even though the velocity potential does not increase but is neutrally stable.

AMR 13-4656

G-59. Gütter, G.

Gütter, Gerhard.
A CENTRIFUGAL ATOMIZER FOR LIQUID AND COLLOID SOLID FUELS. 23 May 62 [5]p.
FTD-TT-62-483.
Order from OTS or SLA $1.10 62-32513

Unedited rough draft trans. of Soviet patent no. 134641, 620929/25, cl 46f, 14; subscript. gr. no. 197, appl 3 Mar 59.

DESCRIPTORS: Liquids, Colloids, Solid, *Fuels, *Atomization, Combustion, Gas turbines, Combustion chambers.

This centrifugal atomizer for liquid and colloid solid fuels burned in the combustion chambers of gas turbines consists of a cone-shaped atomizer body which rotates in a fixed case. It has the following special feature: the body is made in the form of a cup wheel on a circular projection from the drive shaft. On the fuel-intake side it has an annular cavity to receive and accelerate the fuel; on the combustion-chamber side it has a cavity with a double cone whose generatrices diverge toward the combustion chamber; both cavities are separated by a wall and intercommunicate through inclined apertures whose axes diverge toward the combustion chamber. In variant of this the case has fuel-feed channels inclined toward and tangent to the axis; these feed fuel to the annular cavity of the atomizer body.

T8-1152

G-60. Gwyn, J. E., E. J. Crosby, and W. R. Marshall

"Bias in Particle-size Analyses by the Count Method." I&EC Fund. 4, no. 2, 204-8 (May 1965).

H-1. Haas, F. C.

A65-13328
STABILITY OF DROPLETS SUDDENLY EXPOSED TO A HIGH VELOCITY GAS STREAM.
Frederick C. Haas (Cornell Aeronautical Laboratory, Inc., Buffalo, N.Y.).
A.I.Ch.E. Journal, vol. 10, Nov. 1964, p. 920-924. 9 refs.
Sandia Corp. Contract P.O. No. 51-1136.

Combined experimental and theoretical analysis of the breakup of droplets suddenly exposed to a high velocity gas stream such that a velocity differential exists between the liquid and the gas. Analyses are made of the critical size above which all liquid globules will break for given environmental conditions, the time required for breakup for larger-than-critical bodies, and the distortion of such bodies during breakup. Photographs of mercury-drop breakup indicate that disintegration of a droplet near critical conditions occurs in distinct phases: the drop becomes deformed to a thin wafer which remains at constant shape and size for a given time, then forms into an inflated bag with a heavy ring of material at the base, and finally breaks. The times required for these different phases to occur are found experimentally. A preliminary analysis of breakup at low Re (10) is presented.

A65-13328, 04-12

H-2. Haase, L. W.

Haase, L. W.
FINE DISPERSION OF MEDICATIONS WITH INERT GAS. [1960] 13p.
Order from SLA mi$2.40, ph$3.30 60-16601

Trans. of Z[eitschrift für] Aerosol-Forschung [und-] Therap[ie] (West Germany) 1957, v. 6, p. 202-210.

T4-250

H-3. Haenlein, A.

Über den Zerfall eines Flüssigkeitsstrahls (On the Disruption of a Liquid Jet). A. Haenlein. Forsch. (Germ:) Vol. 2 (1931), pp. 139–149, 18 fig. Translation: NACA Tech. Memo 659 (1932), 19 p., 18 fig.

Efflux of liquids of various density, viscosity, and surface tension (namely, water, gas oil, glycerine and castor oil) under various conditions, with respect to jet diameter and efflux velocity. Photographs were taken with the aid of electric sparks, at velocities of 6 to 230 feet per second. Requirements for obtaining similar sprays are discussed on the basis of the principle of similitude. Photographs show waviness of liquid jet surface prior to actual breaking up into drops. At the low speeds employed, with high viscosity liquids (glycerine and castor oil) no atomization was obtained. Discusses (1) drop formation accomplished solely by the surface tension of the liquid, (2) drop formation where the surface tension is reinforced by air action, (3) wave formation by the air, (4) sudden and complete disintegration of the jet. Nozzles of 0.1 to 2.0 mm. diameter and of L/d = 10 ratio were investigated.

deJ I-135

H-4. Hagerty, W. W., and J. F. Shea

190. Hagerty, W. W., and Shea, J. F., A study of the stability of plane fluid sheets, *J. appl. Mech.* 22, 4, 509-514, Dec. 1955.

The fluid sheet issuing from a nozzle can develop spray as a result of ripples or waves that destabilize the sheet. If the frequency and wave length of these waves were known, it might shed light on the size and spatial distributions of the drops in the spray. A stability problem which the authors were able to solve is that of a plane sheet of fluid flowing through another fluid of different density with surface tension at the interfaces. The solution was obtained by assuming that the parallel sides of the sheet are vibrating sinusoidally about their equilibrium position and then applying a stability analysis using classical hydrodynamic velocity potentials. A boundary condition at the interfaces involving both pressures and surface tension is satisfied. It is shown that two types of waves can exist, sinuous waves in which both sides of the sheet oscillate in phase, and dilation waves in which they oscillate out of phase. For all frequencies less than a given frequency, depending among other things on sheet velocity, both types of waves are amplified, but the sinuous waves are amplified more strongly than the dilation waves.

Experimental measurements were made with a nozzle producing plane sheets of water to determine the wave structure and the growth rates (amplification) of waves introduced into the sheet at the nozzle. The sinuous waves dominated the sheet, and the experimental growth rates agreed very well with the theoretical rates for sinuous waves. However, some of the photographs of the waves make the reviewer wonder how accurately the growth rate can really be determined. Some discussion of this point should have been included. The authors are unable to account for apparently self-induced waves that were not deliberately introduced into the sheet at the nozzle.

AMR 10-190

H-5. Hagerty, W. W., and R. A. Yagle

The Rapid Spray Analyzer. W. W. Hagerty and R. A. Yagle. Eng. Res. Inst., U. of Michigan, 1951. 27 p., 13 fig.

Instrument consists of a rotating probe which penetrates the spray cone and makes a point by point traverse around the periphery of the spray. The impinging spray exerts a momentum on the probe which is measured by strain gages mounted on the probe and recorded by a Brush recorder. Analyzer especially suited for rapid check of nozzles for spray symmetry. Sketches, photographs, circuit diagrams, and sample records.

deJ I-135

H-6. Hagerty, W. W., R. A. Yagle, and M. R. El-Saden

The Design of Pressure-Atomizing Swirl-Chamber Spray Nozzles. W. W. Hagerty, R. A. Yagle, and M. R. El-Saden (Univ. Michigan, Ann Arbor, Mich.). Wright Air Development Center, Tech. Rep. 56–472, Feb. 1957. 31 p., 14 fig., 4 ref.

Presents design information for pressure-atomizing spray nozzles, mainly for the range and conditions of turbojet engines. Discusses nozzles of the simple swirl-chamber type, and of the dual-flow type, with positive and with negative axial flow. Nozzle performance is given in terms of nozzle geometry, and of physical properties of the sprayed liquid. Theory of such nozzles is reviewed; theoretical prediction and actual performance are compared to show the extent of agreement for a given range. Sample design is worked out to illustrate use of equations and data. Design relationships are presented analytically and graphically: (1) pressure drop vs. flow rate, (2) cone angle, (3) drop size, for various conditions.

deJ II-206

H-7. Hagerty, W. W., et al.

Continuous Fuel Sprays. W. W. Hagerty, R. A. Yagle, D. R. Glass, M. R. El-Saden, J. F. Shea, and S. H. Reich (Engng. Res. Inst., Univ. Michigan, Ann Arbor, Mich.). U.S. Air Force Tech. Rep. No. 6067, Part 3, Dec. 1952 (Contr. No. W33-038-ac-21230; RDO No. 540—68); 91 p., 79 fig., 27 ref. Part 4, July 1954 (Contr. AF33-616-295); 83 p., 73 fig.

Part 3 discusses basic problems in fuel-spray research. Progress is summarized on (1) disintegration of flat and conical liquid sheets and flow through swirl-chamber nozzles; (2) combustion studies; (3) development of a rapid spray analyzer; (4) photographic technique. Measurements were made on size distribution of spray drops, on spatial location of drops of various sizes, and velocity of drops of various sizes, and velocity of drops. A spray analyzer was constructed which gave a quick evaluation of hollow-cone nozzles by measuring the force of the spray at various locations in its cone; a permanent record of patternation was obtained for each test. Cone angle was measured with an attachment. Presents description of fluid behavior within the swirl chamber, and of spray formation after fluid emergence from the chamber to form a hyperboloid sheath. Over-all burning efficiency of the combustion chamber was substantially constant for wide variations in patternation of a given nozzle over a range of conditions. Relatively hot regions were produced with uneven patternation which may cause hot spots and temperature stratification in the gases striking the turbine blades. Variations in the incoming air-flow patterns produce effects similar to those of faulty patternation.

Part 4 continues the analysis of the simple swirl-chamber nozzle, and experimental data were obtained which relate its performance in terms of fuel flow, pressure drop, mean drop size, and geometry. Derived expressions for cone angle and pressure drop showed satisfactory agreement with experimental results; also the derived expression for the mean drop size after changing the exponent for one term. Preliminary analyses were made of the dual-flow nozzle which relate flow rate and cone angle in terms of the pressure and geometry. Within simulated altitude of 35,000 ft. there was little difference in combustion performance whether the fuel was sprayed in coarse or fine drops. There is considerable dependence on drop size in starting the burner; a high proportion of small droplets is necessary to avoid excessively hot starts. Investigation of stability of a flat thin sheet with air on both sides revealed that a sinuous type of wave caused the breakup of the sheet, in contrast to the dilatational wave acting in a sheet having only one free surface.

deJ II-206

H-8. Hamilton, C. C., and C. M. Smith

"A Colorimetric Method for Showing the Distribution and Quantity of Lead Arsenate Upon Sprayed and Dusted Surfaces," J. Econ. Ent. 18, No. 3, 502-8 (1925).

H-9. Hansell, C. W.

Jet Sprayer Actuated by Supersonic Waves. C.W. Hansell. U.S. Pat. 2,512,743 June 27, 1950. (Assigned to Radio Corp. of America).

A conical nozzle of very acute cone angle is connected to a source of liquid and a piezo-electric high-frequency ultrasonic generator, whereby droplets of about 0.01 cm. dia. are produced at a rate of 15 millions per sec. The liquid remains free of voids. Intended for coating the sensitive screen of television tubes, but usable also as an airbrush, for striping and finishing in industry. Patent shows several modifications of nozzle.

deJ II-208

H-10. Hansen, R. S.

1021. Hansen, R. S., The theory of vibrating jets in liquids of variable surface tensions, *Iowa St. Coll. J. Sci.* 30, 2, 301-311, Nov. 1955.

The theory of jet oscillations in a liquid of time-dependent surface tension has been analyzed. To the extent that the surface tension change can be represented as linear over a single wave length, the wave length is approximately that given by the non-time-dependent equations with surface tension constant at the mean value over the wave length. A high-frequency low-amplitude oscillation will be superimposed on the principal jet motion, which should, however, present negligible complications under usual experimental conditions.

AMR 9-1021

H-11. Hanson, A. R.; E. G. Domich and H. S. Adams

23859 SHOCK TUBE INVESTIGATION OF THE BREAKUP OF DROPS BY AIR BLASTS.
A.R.Hanson, E.G.Domich and H.S.Adams.
Phys. of Fluids (USA), Vol. 6, No. 8, 1070-80 (Aug., 1963).
The breakup of drops exposed to blasts of air is studied in a shock tube. Results are obtained for water, methyl alcohol, and three viscous oils. An acoustical drop holder has been developed in which radiation pressure is used to support the drops at rest in the shock tube. Photographs showing new details in the breakup process are presented.

PA 66-23859

H-12. Harmon, D. B.

7736. Drop sizes from low speed jets. D. B. HARMON, JR. *J. Franklin Inst.*, 259, *No.* 6, 519-22 (*June*, 1955).

Previous theoretical work predicting the drop size to be expected from a slow-speed jet is extended to the case in which the jet issues from a nozzle of sufficient length to assure fully developed laminar flow in the jet as it issues from the nozzle. It is shown that for a real liquid the jet contracts and the flow average velocity of the jet increases. Comparison of the theory with a single experimental result is made.

PA 58-7736

H-13. Harmon, D. B.

1508. Harmon, D. B., Jr., An equation for predicting a mean drop size in a high-speed spray, Univ. Calif. Publ. in Engng. 5, 5, 145-158, 1955.

An equation is developed which can be used under specified conditions to predict the volume-to-surface mean drop size in a high-speed spray issuing from a cylindrical nozzle. The equation is obtained from an energy balance by the use of dimensionless ratios and data from other investigators. The method may be applied to finding an equation for any type of nozzle. The conclusion is drawn that drag is the fundamental drop-forming mechanism for the range of data available and the type of jet investigated. The drop diameter increases with increasing gas viscosity and decreases with increasing liquid density and surface tension. Author believes that the equation derived is suitable for the prediction of the Sauter mean drop size in a high-speed spray such as issues from a cylindrical nozzle in a diesel engine, and even to velocities as low as those occurring in rocket motor injectors. The equation is not applicable to gas pressures below atmospheric, nor to swirl sprays, in which both lineal and rotatory kinetic energies occur.

AMR 9-1508

H-14. Harvey, J. F., and A. S. Hermandorfer

The Design of Constant and Variable-Capacity Mechanical Oil Atomizers. J. F. Harvey and A. S. Hermandorfer. Trans. Soc. Nav. Arch. Mar. Eng., Vol. 51 (1943), pp. 61–82, 19 fig.

Mathematical analysis of the flow conditions and oil-spray characteristics of swirl chamber nozzles; hydrodynamic considerations, vortex flow, path of particle through swirl chamber, capacity, atomization; spray angle; results of tests (spraying water), and design data. Consideration of wide-capacity atomizers and their limitations. Steam atomizing nozzles.

deJ I-142

H-15. Hasson, D., and J. Mizrahi

5617. Hasson, D., and Mizrahi, J., The drop size of fan spray nozzles: measurements by the solidifying wax method compared with those obtained by other sizing techniques, *Trans. Inst. Chem. Engrs.* **39**, 6, 415–422, 1961.

Spraying of liquids is used in numerous physical and chemical processes occurring between the liquid and the gas phase, such as spray drying, humidification, absorption, combustion. The fundamental characteristic of the atomized liquid is its drop-size distribution; but this is difficult to measure accurately. The initial drop-size distribution, created at the first moment of breakup, may change along the path of the spray (by further breakup or by coalescence); it may also be altered during the sampling and sizing operations. Usual method of drop-size determination consists in capturing of a small sample of the spray on some matrix material, and subsequent visual or photographic sizing of the drops. Drawbacks are that the sample may not be representative of the total spray, and that the sizing and counting involves much painstaking labor. Some of these drawbacks are eliminated by the "substitute-liquid" method in which a molten substance is used which simulates the physical properties of the liquid whose drop size is to be measured. Paraffin waxes have been used as substitutes for liquid fuels; the drops solidify after atomization, yielding a powder which can be conveniently sized by sieving and other established solid-particle techniques. There is doubt whether the drop-size determinations by the solidifying spray method are in agreement with those by a sample capturing method. This doubt is justified because: (a) the sampling procedures are dissimilar; (b) the principles of sizing differ—weight analysis involved in one case, number-count analysis in the other; (c) there is a possibility that the two methods might measure different physical entities altogether.

This paper reports on carefully executed experiments to throw light on this problem, by comparing results obtained by the two methods. It is found that the solidifying spray method yields results systematically lower by 30% compared with those measured by the sample-capture method. This is explained by the existence of a coalescence region, immediately following the break-up zone, in which drop size increases by the recombination of colliding liquid drops, and the rapid solidification of the wax drops before passing through all of this region. Expressions are given for the surface mean diameter as well as for drop-size distribution fitted according to the Rosin-Rammler function. Authors conclude that both methods are useful: the sample-capturing method represents the spray past the coalescence zone, therefore it is best suited for applications in which the final spray is of interest, such as agricultural spraying and some mass-transfer operations; the solidifying-spray method represents the spray in the initial part of the disintegration zone, therefore it is best suited for spray drying and combustion applications. This is a well-considered informative paper based on the extensive spray researches of the Imperial College of Technology, London, and on the authors' studies and experiments at Technion, Israel.

AMR 15-5617

H-16. Hasson, D., and R. E. Peck

5830. Hasson, D., and Peck, R. E., Thickness distribution in a sheet formed by impinging jets, *AIChE J.* **10**, 5, 752–754, Sept. 1964.

Paper gives neat analytical solution to the problem of the thickness of the liquid sheet formed as the first stage of break-up in an atomizer consisting of two equal cylindrical jets impinging on each other. The equation: $hr/R^2 = \sin^3\theta/(1-\cos\phi\cos\theta)^2$ is derived where h = sheet thickness, r = radial distance in the sheet from the stagnation point of jet impingement, R = jet radius, θ = half total jet impingement angle, ϕ = angular position. Very good agreement is shown with the experimental results of K. D. Miller [*J. Appl. Phys.* **30**, 1950, 1959] and G. I. Taylor [*Proc. Roy. Soc. London A.* **259**, 1, 1960].

AMR 18-5830

H-17. Hausser, F., and G. M. Strobl

Die Messung der Tropfengröße bei zerstäubten Flüssigkeiten (Measurement of drop size in atomized liquids). F. Hausser and G. M. Strobl. Z. Techn. Phys. Vol. 5. No. 4 (1924), pp. 154–157.

Method of catching drops on a surface, and defining the drop-size distribution by curves.

deJ I-143

H-18. Hawthorne, W. R.

"Notes on Atomizer Research Done by Prof. Hottel at M.I.T., USA," Royal Aircraft Estab., Tech. Note ENG. 167, June, 1943, 5 p. Report No. N-6004.

H-19. Heath, H., and A. Radcliffe

"The Performance of an Air Blast Atomizer," Nat. Gas Turb. Estab., Report No. 71, 19 pp., 13 figs., June 1950.

H-20. Hege, H.

"Liquid Dispersion by Means of Centrifugal Disks," Hermann Hege (Tech. Hochschule, Munich, Ger.). Chem. Ingr. Tech. 36(1), 52-9(1964).

CA 60-10235h

H-21. Heidmann, M. F.

N62-11878 National Aeronautics and Space Administration. Lewis Research Center, Cleveland.
PHOTOGRAPHY AND ANALYSIS OF TIME VARIATION IN DROP SIZE DISTRIBUTION OF A LIQUID SPRAY.
Marcus F. Heidmann. Repr Paper N-7 from the Proc. of the 5th Intern. Congr. on High Speed Photography, Oct. 22. 1960. p. 519-524. 6 refs.

High-speed backlighted pictures of a finite area in the spray of two impinging water jets were taken to examine the effect of sample size on drop-size distribution by pseudo-continuous sampling and to analyze the nature of time variations occurring in a steady-state disintegration process. The optical system included a stroboscopic light source with spark discharge of less than 1-μsec duration and a 35 mm drum camera of 5-ft circumference. Continuous sampling was simulated by essentially matching spray and film velocity (500 in/sec) in 1X photographs taken 500 times/sec. A film velocity of 3000 in/sec and light flashing rate of 10,000/sec were used to study time variations. An electronic particle analyzer with electron beam scanning and digital output was used for drop counting. A total of about 300 photographs containing nearly 35,000 drops were analyzed for these studies. Drop-size distributions were bimodal in nature and required an accumulation of at least 10,000 drops to develop fully. Random variation with major perturbation in all drop sizes occurred about 1000 times/sec or every 0.2 in along the flow path.

N62-11878, 06-11

H-22. Heidmann, M. F., and H. H. Foster

553. Heidmann, M. F., and Foster, H. H., Effect of impingement angle on drop-size distribution and spray pattern of two impinging water jets, NASA TN D-872, 34 pp., July 1961.

This is part of the extensive spray investigations of the National Aeronautics and Space Administration, dealing with atomization problems of rocket-engine combustors. Authors investigated the spray formed by two 0.089-inch-diameter water jets, for impingement angles of 10 to 90 degrees, and jet velocities of 30 to 74 ft/sec. Photographs of overall spray pattern formed in quiescent air show greater dispersion and reduced liquid sheet length for larger impingement angles. Drop-size distributions were obtained with the spray formed in a 100-foot-per-second airstream. Drop counts were made from shadowgraph photographs, using an electronic particle analyzer. All distributions showed bimodal characteristics, with number-median diameters of about 200 and 600 microns for the two modes.

The most significant effect of impingement angle and jet velocity on the distribution was a change in the relative number of drops in each mode, and the geometric mean deviation of the larger drop-size mode; this effect was most pronounced at low jet velocities. Mass-median diameters and relative mass in the two modes were determined from the basic number-size distributions, and the effect of angle and velocity was evaluated. At all test conditions the larger drop-size mode contained the majority of mass. Overall volume-number mean and mass-median drop diameters were obtained for each condition. Both parameters increased with a decrease in impingement angle, the largest increase occurring at low jet velocities.

The apparatus used is clearly illustrated and described. Numerous pictures are shown of sprays taken at various velocities and impingement angles, also micrographs of drop-size distributions and the corresponding drop-size spectra showing their bimodal characteristics. Graphs of the statistical evaluation of the experimental data are given. Bibliographic references are given of related research conducted mainly by NASA, but also by other investigators.

AMR 15-533

H-23. Heidmann, M. F., and J. C. Humphrey

168. Heidmann, M. F., and Humphrey, J. C., Fluctuations in a spray formed by two impinging jets, *J. Amer. Rocket Soc.* **22, 3**, 127-131, 167, May-June 1952.

Paper is part of investigation to study relationship, if any, between fluctuations in spray formation and combustion instability in liquid-fuel rocket motors. Two impinging jets of water were observed by microflash photographs, with variations in jet velocity, jet diameter, impingement angle. Ruffled sheet of liquid is formed at point of impingement, perpendicular to plane of jets, and this liquid sheet disintegrates intermittently, forming groups of drops which appear as waves propagating from the point of impingement. The frequency of propagation varied between 1000 and 4000 cps for range of test conditions, and was approximately proportional to velocity in liquid sheet. Reviewer considers this an interesting paper, showing that combustion instability may arise from fuel supply system, even when the supply pressure is constant.

AMR 6-168

H-24. Heidmann, M.F., and J. C. Humphrey

3605. Heidmann, M. F., and Humphrey, J. C., Fluctuations in a spray formed by two impinging jets, *Nat. adv. Comm. Aero. tech. Note* 2349, 35 pp., Apr. 1951.

Upon impingement of two jets, a ruffled sheet of liquid forms perpendicular to the plane of the two jets. The liquid sheet disintegrates intermittently, forming a group of drops that appear as waves propagating from the point of impingement. The intermittent disintegration of the liquid sheet results in irregular spacing between waves and in variable wave intensity. There is an abundance of small waves, with the number of waves above a given intensity decreasing as the intensity increased.

The frequency of wave formation is constant over a finite time interval under constant operating conditions. The frequency varied between 1000 and 4000 cps for the range of test conditions used in this investigation. An increase in jet velocity results in an increase in wave frequency, the relation approaching a direct proportionality. For the jet diameters and velocities used in this investigation, an increase in jet velocity of 60 fps resulted in an increase in frequency of approximately 2500 cps. An increase in impingement angle results in a decrease in wave frequency for impingement angles of from 50° to 100°. The decrease in frequency with impingement angle is approximated by the decrease in the cosine of one-half the impingement angle.

A diameter change from 0.025 to 0.057 inch has a negligible effect on wave frequency compared to the effect of jet velocity and impingement angle. A change in jet length from 10 to 80 diameters before impingement has a negligible effect on wave frequency.

From the photographic and frequency data obtained, it appears that ruffling of the liquid sheet persists to the point of disintegration and determines the frequency of the wave formation, and that irregularities in the jets before impingement may be as instrumental in controlling the ruffling of the liquid sheet as is the friction of the air.

AMR 4-3605

H-25. Heidmann, M. F., et al

3672. Heidmann, M. F., Priem, R. J., and Humphrey, J. C., A study of sprays formed by two impinging jets, *NACA TN* 3835, 32 pp., Mar. 1957.

The spray formed by two impinging liquid jets was investigated over a jet velocity range of 5 to 100 fps to determine the characteristics of this method of atomization. At low velocities, the spray pattern was a smooth sheet completely surrounded by a liquid rim. As jet velocity increased, the rim separated at the downstream end. In this flow region an alternate spray pattern with a rippled sheet and periodic drops can occur. At higher jet velocities, a fully developed spray was produced which was characterized by waves of drops. The wave pattern was more distinct with high-viscosity fluids. The frequency of the waves in the fully developed spray increased with increasing injection velocity and decreasing impingement angle. Jet diameter and length before impingement had a negligible effect on the wave frequency. Characteristics of single jets were the same as determined by other investigators.

The liquid jets were formed with 2-in. lengths of precision-bore glass tubing of 0.025-, 0.040-, and 0.051- in. inside diam; they were oriented toward each other by a protractor device, and liquid was fed to them from two liquid containers pressurized from a common pressure gas cylinder. Variable parameters were: flow rate, impingement angle, jet diameter, and jet length before impingement. Both high-speed motion pictures (3000 frames per sec) and single-exposure microflash photographs of approximately 4-microsecond exposure were taken. The intermittent disintegration was observed and recorded by a photoelectric apparatus.

AMR 10-3672

H-26. Heinrich, D., and B. Dräger

"Centrifugal Atomizer for Liquids," German Patent 1,021,300, Dec. 19, 1957.

H-27. Helmholtz

Phil. Mag. Vol. 36 (1868).

Treats the instability of boundary surfaces separating portions of fluids which move discontinuously. (See RAYLEIGH 1879.)

deJ I-148

H-28. Hendricks, C. D.

N64-19840 Illinois U., Urbana
CHARGED PARTICLE PROPULSION: A DOUBL. NERGY-CONVERSION PROBLEM
Charles D. Hendricks *In* Argonne Natl. Lab. AMU-ANL Conf on Direct Energy Conversion, Nov. 4-5, 1963 Dec. 1963 p 89-99 (See N64-19826 12-01) OTS: $2.75

An electrically sprayed liquid-droplet source of heavy particles was investigated. The parameters that were found to affect the spraying process are flow rate, capillary diameter, spraying potential, conductivity, viscosity, temperature and surface temperature. Specific charge distributions are included for glycerine and carbon-glycerine sprays, and dibutyl phthalate spray

N-64-19840, 12-27

H-29. Hendricks, C. D.

11346 CHARGED DROPLET EXPERIMENTS.
C.D.Hendricks, Jr.
J. Colloid Sci. (USA), Vol. 17, No. 3, 249-59 (March, 1962).

The velocity and charge of individual charged droplets of oil accelerated through 12 and 13 kV have been measured. From these measurements, the oil density, and the accelerating potential, computations were made of the charge-to-mass ratio, the mass, and the radius of the droplets. The charge-to-mass ratios were 0.01 to 5 coulombs per kilogram and the droplet radii were 0.1 to 10 microns. The charged oil droplets were produced at the point of a hollow stainless steel needle maintained at a high (12-13 kV) positive potential. Rayleigh's theory on the instability of charged liquid drops predicts a maximum limit of charge-to-mass ratio as a function of radius above which the drops become unstable. The maximum observed charge-to-mass ratios of the oil drops at any radius were found to lie very close to the theoretical curve predicted by Rayleigh's theory. This limit was about a factor 50 below the field emission limit predicted on the basis of Muller's work (Abstr. 5158 of 1956) on field emission.

PA 65-11346

H-30. Hendricks, C. D.

Hendricks, C. D., Jr.

"Charged Droplet Experiments," Second Symposium on Adv. Propulsion Concepts, ARDC and AVCO-Everett Res. Lab., Boston, Massachusetts (October 1959).

Experimental techniques for the measurement of charge-to-mass ratios and drop size of electrostatically charged droplets discussed. High potential hollow needles produced electrostatic atomization of octoil. Distribution of radii and charge-mass ratio given, as well as distribution of droplet charge. Size was concentrated in 1 to 4 micron range.

Author

H-31. Hendricks, C. D., R. S. Carson, J. J. Hogan, and J. M. Schneider

"Photomicrography of Electrically Sprayed Heavy Particles." AIAA Electric Prop. Conf., Colorado Springs, Mar. 11-13, 1963. Paper no. 63051-63.

Preliminary analysis of space flight trajectories has shown that electrostatic thrust devices using particles with charge-to-mass ratios in the range of 10^2 to 10^5 coulomb/kilogram would permit achievement of payload optimization quite readily. In addition, beam neutralization problems would be minimized. The research discussed in this paper is presently aimed at furthering the general knowledge of charged droplet production and behavior by studying the effects of such physical properties as density, viscosity, conductivity, and surface tension, on the charge-to-mass ratio distribution. In this paper, high speed photomicrographs of surface instabilities are presented and discussed and Rayleigh's theory on the instability of charged droplets is extended to include droplet emission.

Author

H-32. Hendricks, C. D., and J. M. Schneider

14503 STABILITY OF A CONDUCTING DROPLET UNDER THE INFLUENCE OF SURFACE TENSION AND ELECTROSTATIC FORCES. C.D.Hendricks and J.M.Schneider. Amer. J. Phys. Vol.31, No.6, 450-5 (June, 1963).

The Lagrange equations of motion are written in generalized coordinates which describe small departures from the spherical equilibrium configuration of a conducting liquid droplet. It is initially assumed that the actual shape differs only very slightly from the equilibrium sphere. The equation representing the surface is, then, written as a series of surface zonal harmonics in which the coefficients are shown to be the normal coordinates of the droplet. The frequency of oscillation of the normal coordinates is shown to depend on the total charge on the droplet in such a manner that for all values of charge below a certain limit, the frequency is real. For all values of charge above a certain limit, the frequency is imaginary; and, thus, the droplet is unstable. This paper presents a detailed derivation of a result communicated by Rayleigh in 1882. The results of Rayleigh's communication have been widely quoted but, until now, this particular derivation has not appeared in the literature.

PA 66-14503

H-33. Hendrickson, R. M.

Bibliography on Methods of Producing Aerosols, Vapors, and Gases at Test Atmospheres. Ruth M. Hendrickson. Publ. Los Alamos Scientific Lab., Los Alamos, N.M., May 20, 1958, 44 p., 165 ref. (AECU-3915; D-BIB-26).

Covers period 1928–1958, based on following sources: AMA Archives of Industrial Health, 1956–1957; Bulletin of Hygiene, 1956; Engineering Index, 1958; Industrial Hygiene Digest, 1956–1957; Nuclear Science Abstracts 1956–1957; Public Health Engineering Abstracts, 1949–1958; STREHLOW 1951; SCHEFFY 1956.

deJ II-215

H-34. Herring, W. M., and W. R. Marshall

"Performance of Vaned-Disk Atomizers."
W. M. Herring, Jr., and W. R. Marshall, Jr. (Univ. of Wisconsin, Madison). Am. Inst. Chem. Eng. J. 1, 200-9 (1955).

CA 49-10678e

H-35. Herrmann, R.

"Atomizers for Emission and Absorption Flame Photometry."
R. Herrmann (Univ. Clinics, Giessen, Ger.). Optik 18, 422-30 (1961).

CA 57-606h

H-36. Heubner, W.

"On the Measurement of Droplet Size in Atomized Liquids," Zeits. Tech. Phys. 6, 149 (1925).

H-37. Hidy, G. M.

"On the Theory of the Coagulation of Noninteracting Particles in Brownian Motion," J. Colloid Sci 20, 123-44 (1965).

The theory for coagulation of particles in Brownian motion is reviewed. The effects of heterogeneity in particle size, and of particle motion in a rarefied medium are examined using numerical solutions of the coagulation equations. Heterogeneity and increased values of the ratio of the mean free path of the medium to the particle radius (the Knudsen number for particles) increased the rate of coagulation. According to the results of the numerical experiments, a self-preserving function for the size distribution develops after dimensionless coagulation times of about 3. The self-preserving spectrum was found to be independent of the initial distribution after a sufficiently long time. The shape of the asymptotic distribution varied with the ratio of the mean free path of the medium to the particle radius (λ/r_i). A cumulative distribution rapidly formed which was insensitive to time, to initial conditions, and to variations in λ/r_i up to one. The average cumulative distribution compared fairly well with an experimentally determined distribution.

Author

H-38. Hill, T. L.

Concerning the Dependence of the Surface Energy and Surface Tension of Spherical Drops and Bubbles on Radius. T. L. Hill. Jl. Am. Chem. Soc. Vol. 72 (1950), pp. 3923–3927.

The approximate model used by Fowler to investigate theoretically the surface energy and surface tension of a plane liquid surface is extended to spherical drops and bubbles, assuming liquid incompressibility. It is possible to derive an expression for the correction of the plane surface tension for curvature, which predicts that the surface tension decreases with radius. The magnitude of the effect is small in this zero-order approximation.

deJ I-152

H-39. Hinrichs, B. R.

"Atomization of Water in Multi-Purpose Nozzles at Pressures up to 355 psi," VFBD Forsch. u. Tech. im Brandschutz 12, 14-17 (1963), for English summary, see: Fire Res. Absts. and Revs. 5, No. 3, 198-200 (1963).

H-40. Hinze, J. O.

3278. Hinze, J. O., Fundamentals of the hydrodynamic mechanism of splitting in dispersion processes, *AICHE Journal* **1, 3,** 289-295, Sept. 1955.

The splitting of globules is an important phenomenon during the final stages of disintegration processes. Three basic types of deformation of globules and six types of flow patterns causing them are distinguished.

The forces controlling deformation and breakup comprise two dimensionless groups: a Weber group, and a viscosity group. Breakup occurs when the Weber number exceeds a critical value. Three cases are studied in greater detail: (a) Taylor's experiments on the breakup of a drop in simple types of viscous flow: (b) breakup of a drop in an air stream: (c) emulsification in a turbulent flow. It is shown that the critical value of the Weber group depends on the type of deformation and on the flow pattern around the globule. The interrelationship between the three cases and the value of the Weber group is investigated. A formula is derived for the maximum drop size.

AMR 9-3278

H-41. Hinze, J. O.

300. J. O. Hinze, Critical speeds and sizes of liquid globules, Appl. sci. Res. Sec. A, 1, no. 4, 273-288 (1949).

Splitting up of a liquid globule that has a translatory motion relative to air depends upon the interplay between the air resistance and the surface tension, and therefore upon Weber's number: the drop splits up if this number exceeds a critical value, which for falling drops is different from that for drops suddenly exposed to a flow of constant speed. The paper indicates a relation between the two cases, based on the consideration of the critical value of the deviation of the drop from spherical shape at the point of stagnation. The theory is based upon formulas, derived by the author in the preceding paper, for the slight deformation of a liquid globule, caused by normal forces on its surface (neglecting the effect of tangential stresses on deformation), and has therefore only a formal meaning; approximate expressions for the deviation as a function of Weber's number are derived for both situations and for very slight (i.e., the usual) or very large effect of the viscosity of the liquid. Recent experiences of Merrington and Richardson on falling drops have furnished a critical Weber's number of about 10; the corresponding value for the case of sudden exposure to an uniform flow should be about 6.

AMR 3-300

H-42. Hinze, J. O.

290. J. O. Hinze, Forced deformations of viscous liquid globules, Appl. sci. Res. Sec. A., 1, no. 4, 263-272 (1949).

The author studies the deformations of liquid globules having a translatory motion relative to air, as may occur, for instance, during distintegration processes of high-speed liquid jets and for falling drops, the effect of viscosity being taken in consideration. The problem is restricted to slight deviations from the spherical shape and therefore the equations of the motion of a viscous incompressible fluid are simplified by omitting nonlinear terms. The boundary conditions at the surface of the globule, consistent with its translatory motion relative to air, consist of zero tangential stress and a prescribed external pressure distribution of rotational symmetry. The motion of the liquid is supposed to have the same rotational symmetry. Two solutions are obtained for the cases of slight and large viscosities. For the other cases no solutions are obtained; it is then necessary to solve a complicated auxiliary equation. In the case of slight viscosity the damping coefficient found by the author differs from that calculated by Lamb who uses a different method (*Hydrodynamics*, 6th ed., art. 355, New York, 1945), and reasons are given for which Lamb's result cannot be correct.

AMR 3-299

H-43. Hinze, J. O.

On the Mechanism of Disintegration of High-Speed Liquid Jets. J. O. Hinze (N. V. de Bataafsche Petroleum Mij., Proefstation Delft, Holl.). Paper at 6-th Intern. Congr. Appl. Mech., Paris (July 1946), 8 p., 15 ref.

Using known concepts of turbulent flow, the formation and development of surface disturbances of a jet into ligaments, the splitting-up process of droplets, etc. as developed by Rayleigh, Weber, Castleman, Schweitzer, Thomson, and others, the author analyses the influences of nozzle dimensions, liquid viscosity, jet velocity, surface tension, air viscosity, air density, etc. on the fineness and uniformity of atomization, supporting his contentions with the experimental results of Sass, Mehlig, Lee, Schweitzer, and Oschatz.

deJ I-152

H-44. Hinze, J. O. and H. Milborn

3293. Hinze, J. O., Atomization of liquids by means of a rotating cup, *J. appl. Mech.* 17, 2, 145-153, June 1950.

This theoretical and experimental analysis of liquid atomization by means of a rotating cup fills a need for information on an important subject. Authors have correlated the important factors involved and obtained workable relationships. Problem dealt with concerns the disintegration of a liquid fed through a stationary tube to the inner surface of a rotating cup which widens to a brim. The film on the inner surface has been found to flow viscously. Authors have determined the thickness of this film in terms of readily measured constants. The nature of the disintegration phenomenon itself has been carefully studied, and three types have been noted: (1) Direct drop formation; (2) ligament formation and eventual disintegration; and (3) film formation at the cup brim. Causes of these types of disintegration are discussed at length. Relationships between the various states of disintegration are presented in graphs using experimental data, and the critical transition formulas are included. Droplet size of the mist produced was found to conform with the Rosin-Rammler distribution function.

Article contains an excellent account of "ligament" formation. Excellent photographs illustrate the various states of disintegration.

AMR 4-3293

H-45. Hodgkinson, T. G.

"Control by Surface Tension of a Conical Fluid Sheet Jet," Porton Tech. Paper No. 174, Chemical Defence Establishment Directorate of Chemical Defense Res. and Develop., May 18, 1950.

H-46. Hogan, J. J.

N64-20822 Illinois U., Urbana Charged Particle Research Lab.
PARAMETERS INFLUENCING THE CHARGE-TO-MASS RATIO OF ELECTRICALLY SPRAYED LIQUID PARTICLES
James J. Hogan 15 Dec 1963 143 p refs
(Grants AF-AFOSR-107-63, NSF G-19776)
(CPRL-2-63)

The problem in this study was to investigate the parameters influencing and the mechanisms involved in the electrical atomization process, i.e., in the process by which liquid surfaces are broken up into small, charged particles as the result of electrostatic forces. Electrical atomization was studied primarily by measuring the charges, masses, velocities, and charge-to-mass ratios (specific charge) of the particles in the beams thus generated. A theoretical study of the electrical dispersion process is presented. The study includes surface energy minimization of the dispersed system of particles, solution of Poisson's equation and the influence of space charge on the specific charge of the emitted particles, and the influence of the conductivity and temperature of the liquid on the generation of charged particles.

N64-20822, 14-23

H-47. Hogan, J. J. and C. D. Hendricks

A65-18496 #
INVESTIGATION OF THE CHARGE-TO-MASS RATIO OF ELECTRICALLY SPRAYED LIQUID PARTICLES.
J. J. Hogan and C. D. Hendricks (Illinois, University, Dept. of Electrical Engineering, Urbana, Ill.).
AIAA Journal, vol. 3, Feb. 1965, p. 296-301. 13 refs.
Grant No. AF AFOSR 107-64; NSF Grant No. G 19776.

Analysis of the charge-to-mass ratios (specific charges) of particles generated by the electrical atomisation process. The study involves the surface energy of the dispersed systems of particles, the effects of space charge on the source, and the effects of conductivity on the atomisation process. Experimental data are presented in support of these theories. Further, a colloidal suspension in glycerine is experimentally shown to produce particles of high specific charge (400 coul/kg) when electrically dispersed under appropriate conditions.

A65-18496, 08-28

H-48.- Holfelder, O.

Zur Strahlzerstäubung bei Dieselmotoren (Atomization in Diesel engines). O. Holfelder. Forschung (Germ.), Vol. 3 (Sept.-Oct. 1932), pp. 229–240, 38 fig., 17 ref.

Investigations on the break-up of liquid jets from open nozzles and the influence of orifice shape and air pressure. Spark photography. Water was used, with check runs on fuel oil. Conclusions regarding the magnitude of the "initial disturbance" and influence of air density. Nozzles, shape, diameter, discharge coefficient. Spray dispersion at low speed. Vibrating jets. Spray cone angle and penetration. Influence of nozzle shape. Shape of spray in vacuum. Limiting jet velocities were determined as function of the air pressure for the transition from break-up into drops, wave formation, wave formation with spray envelope, and atomization. It was found that under identical test conditions the shape of the orifice determines the spray cone angle and the penetration

deJ I-155

H-49. Holland, T. H.

No Title, Confidential Report, George Washington Univ. Res. Labs. Quarterly Prog. Rept. No. 15 (Project No. 4-04-14-021), Contract No. DA-18-064-404 CML 163, Aug. 15, 1956.

H-50. Holroyd, H. B.

On the Atomization of Liquid Jets. H. B. Holroyd. Jl. Franklin Inst., Vol. 215 (1933), pp. 93–97.

Develops a formula for predicting the mean drop diameter from the nozzle dimensions and liquid characteristics for sprays from plain hole nozzles under the assumption that the flow in the nozzle is turbulent and has a mean angular velocity. Finds fair agreement with the experimental data by KUEHN and LEE. Suggests experiments with molten wax or with molten alloy of low melting point, for drop size determination.

deJ I-156

H-51. Hommelen, J.

"Measurement of Dynamic Surface Tension by the Method of Oscillating Jet and of the Falling Meniscus." Jacques Hommelen. Mém. serv. chim. état (Paris) 41, 267-77 (1956-57); cf. C.A. 51,17351c; 52,19314b.

CA 54-4111h

H-52. Hopkins, J. L.

The Size Distribution of Droplets in a Fuel Spray. J. L. Hopkins. Shell Petroleum Co., Ltd., London, Techn. Rept. No. ICT/6 (1946). 29 p., 7 fig., 24 ref.

Review of methods of drop-size determination and of definition of size distribution. Discussion of the Rosin-Rammler equation and its limitations, derivation from it of various quantities, such as specific surface, specific surface in combustion, initial rate of evaporation, etc.; graphs showing the influence of the Rosin-Rammler size and distribution constants on these quantities. Implications of the assumption that the size distribution extends from zero to infinity.

deJ I-156

H-53. Horgan, J. D. and D. L. Edwards

16239 FORCES IN DIELECTRIC FLUIDS.
J.D.Horgan and D.L.Edwards.
J. appl. Phys. (USA), Vol. 32, No. 9, 1784 (Sept., 1961).
The paper concerns the fountain of dielectric liquid produced by a highly charged needle conductor immersed in the liquid. Experimental work has indicated that the effect is due to ionization of the liquid and is not a polarization effect as has been thought.

PA 64-16239

H-54. Houghton, H. G.

Spray Nozzles. H. G. Houghton. Chem. Engrs. Handbook (J. H. Perry, Ed.) McGraw-Hill, New York 3rd Ed. (1950), pp. 1170—1175, 10 fig.

General treatment of nozzles as used in chemical process industries. Description and discussion of salient features of pressure nozzles (hollow-cone, solid-cone, fan-spray, impact nozzles and "fog" mozzles for firefighting), rotating atomizers and gas-atomizing nozzles. Discharge rates and spray angles for typical pressure nozzles. Drop-size distribution data for three hollow-cone nozzles, and for a small air-atomizing nozzle.

deJ I-157

H-55. Hrubecky, H. F.

526. **Hrubecky, H. F., Experiments in liquid atomization by air streams,** *J. appl. Phys.* **29**, 3, 572-578, Mar. 1958.

Water is atomized by a high-velocity air stream using various methods of injection and water nozzle positions. Low water volume rates and velocities, air velocities up to acoustic, and ratios of air volume to water volume rates up to 25,000 were utilized. Highest degree of atomization was achieved when the water was injected into region of maximum velocity of the air stream, and parallel to it. Comparison is made with the Nukiyama-Tanasawa correlation: discrepancies in droplet sizes at high air velocities are found and discussed.

Experimental apparatus is described, and illustrated schematically; the liquid nozzles were made of hypodermic stainless steel tubing, the drops were received on glass slides coated with magnesium oxide. Results are presented in tables and charts. A list of previous research work is given.

AMR 12-526

H-56. Hrubecky, H. F.

710. **Hrubecky, H. F., Experiments in the air-stream atomization phenomena,** *Heat Transf. and Fluid Mech. Inst.*, 263-274; Univ. of Calif., Berkeley, June 30-July 2, 1954.

This paper concerns the results of tests seeking to relate the degree of atomization to water injection position and orientation in a high velocity air stream. Tests seem to indicate that the greatest degree of atomization is obtained when water is injected parallel to the air flow. The smallest "mean diameters" of droplets occur at the highest air velocities.

The author presents his results in tabular rather than graphical form. During the various runs with parallel injection, author relates droplet diameter to air velocity. Unfortunately, the ratio of air volume rate to water volume rate was permitted to vary so that it is not possible to ascertain how much of the drop-size reduction with increasing air velocity is due to increased relative flow rates.

AMR 8-710

H-57. Hughes, R. R., and E. R. Gilliland

The Mechanics of Drops. R. R. Hughes (Shell Development Co., Emeryville, Calif.) and E. R. Gilliland (M.I.T.). Preprints of Papers at 1951 Heat Transfer and Fluids Mechanics Institute, Stanford U. Press, Stanford, Calif. (1951), pp. 53—72, 7 fig., 28 ref. Also in Chem. Eng. Progr. Vol. 48 (1952) p. 497.

Review and analysis of the mechanics of drops as a preliminary to a general study of mass transfer in fluid particle systems. Included both the gross motion of drops and the detailed motion in and around individual drops. Emphasizes new concepts and correlations in connection with the effect of acceleration on drop, the equilibrium distortion, and the internal circulation caused by skin friction, oscillatory motion of a liquid sphere, eddying inside the drop, and other internal motion caused by oscillation.

deJ I-158

H-58. Huss, H. O.

"Airplane Spray Apparatus, Evolution of the Ram Gravity-Type Smoke Tank." Harry O. Huss (Army Chem. Center, Md.). Armed Forces Chem. J. 3, No. 8, 10-15, 32-3 (1950).

CA 44-5039a

H-59. Hydro-Nitro Soc.

"Apparatus for the Improvement of Bioclimatic Condition of Room Air." Hydro-Nitro Soc. anon.— Swiss 257,883, July 1, 1949 (Cl. 116i).

CA 44-9098a

I-1. Il'yashenko, S. M.

6748. Il'yashenko, S. M., Atomization jets of centrifugal spray burners: Part 1 (in Russian), *Izv. Vyssh. Ucbebn. Zavedenii: Aviats. Tekh.* no. 2, 88–98, 1960; *Ref. Zh. Mekh.* no. 4, 1961, Rev. 4 B 214.

The paper incorporates a short survey of studies devoted to the atomization of liquid fuel by means of centrifugal spray burners. An empirical formula is introduced which is based on the generalization of tests on the spraying of liquids using centrifugal sprayers which were carried out by different investigators

$$\frac{d_m}{d_\Phi} = \frac{x}{\mu_0}\left(\frac{c}{u}\right)^{0.017} \mu_\Phi \sqrt{\frac{p_0}{p}}$$

$$x = (\sigma/\sigma_0^{0.77} + (\nu_r/\nu_0)^{0.44}$$

Here d_m is the median diameter of the droplet, d_Φ the diameter of the nozzle of the spray burner, z the parameter of the fineness of atomization dependent on the properties of the liquids, σ and ν_r the surface tension and the kinematic viscosity of the liquid being atomized, $\sigma_0 = 24\ dn/cm$, $\nu_0 = 2CCT$, μ is the velocity of the liquid relative to the air, c is the local velocity of sound, μ_0 is the coefficient of discharge of the spray burner, p is the air pressure. Formulas are given for the calculations of the jet of unevaporated liquid flowing from the centrifugal sprayer into a flow of air. The results of the calculations for the jets are compared with the experimental data obtained by the author for different conditions of flow of the liquid fuel and for different parameters of the air flow.

AMR 16-6748

I-2. Il'yashenko, S. M.

Il'yashenko, S. M.
JET ATOMIZATION BY CENTRIFUGAL NOZZLES. II. LOCAL FUEL CONCENTRATION IN NON-VAPORIZING JETS [AND] VARIATION OF AXIAL FUEL CONCENTRATION AT INCREASING DISTANCES FROM THE NOZZLE SECTION. [1961] 15p. 7 refs.
Order from LC or SLA mi$2.40, ph$3.30 61-10398

Trans. of Izvestiya Vysshikh Uchebnykh Zavedeniy. Aviatsionnaya Tekhnika (USSR) 1960, no. 3, p. 57-64.

The local fuel concentration in nonvaporizing jets and the variation of axial fuel concentration at increasing distances from the nozzle section are analyzed. (See also 60-18763)

T5-616

I-3. Ingebo, R. D.

"Relation of Atomization and Rocket Combustor Performance." Robert D. Ingebo (NASA Lewis Res. Center, Cleveland, Ohio). Chem. Eng. Progr. 58, No. 4, 74-6 (1962).

CA 57-608d

I-4. Ingebo, R. D.

"Size Distribution and Velocity of Ethanol Drops in a Rocket Combustor Burning Ethanol and Liquid Oxygen." R. D. Ingebo (NASA, Lewis Research Center, Cleveland, Ohio). ARS (Am. Rocket Soc.) J.31, 540-1 (1961).

CA 55-19358e

I-5. Ingebo, R. D.

3827. Ingebo, R. D., Drop-size distributions for impinging-jet breakup in airstreams simulating the velocity conditions in rocket combustors, *NACA TN* 4222, 8 pp. + 1 table + 8 figs., Mar. 1958.

Data obtained with a high-speed camera on heptane sprays produced by pairs of impinging jets in airstreams over ranges of orifice diameter D_j, liquid-jet velocity V_j, and velocity difference between the airstream and the liquid jet ΔV were analyzed by using the Nukiyama-Tanasawa expression

$$dR/dD = (3.915/D_{30})^6 (D^5/120) \exp(-3.915\ D/D_{30})$$

where R is the volume fraction of drops having diameters D, and D_{30} is the volume-number-mean drop diameter. A range of orifice diameters (D_j = 0.029, 0.060, and 0.089 in.), liquid-jet velocities (V_j = 30, 65, and 100 fps), and velocity differences between the airstream and the liquid jets (ΔV = 0 to 235 fps) gave maximum observed drop diameters ranging from 180 to 1160 microns. Values of D_{30} varied from 68 to 347 microns, and the following empirical expression was derived

$$D_j/D_{30} = 2.64\sqrt{D_j V_j} + 0.97\ D_j \Delta V$$

where diameters are expressed in inches and velocities in fps.

Test equipment and the nozzles used are described and illustrated; sample spray photos shown. Results are represented in log-probability, in Rosin-Rammler, and in Nukiyama-Tanasawa charts.

AMR 11-3827

I-6. Ingebo, R. D.

770. Ingebo, R. D., Drag coefficients for droplets and solid spheres in clouds accelerating in airstreams, *NACA TN* 3762, 31 pp., Sept. 1956.

The steps preceding the burning of liquid fuel injected into a combustor, i.e., atomization, acceleration, and vaporization, are important for the design, operation, and performance of jet engines. The droplets formed by atomization simultaneously accelerate and evaporate, giving combustible fuel-air mixtures. In the present investigation, clouds of liquid and solid spheres accelerating in airstreams were studied over a range of airstream pressure, temperature, and velocity conditions. Diameter and velocity data for individual droplets and solid spheres in clouds were obtained with high-speed camera developed at the NACA Lewis Laboratory. From these data, linear accelerations of spheres (20 to 120 microns in diameter) were determined, and instantaneous drag coefficients for unsteady momentum transfer were calculated. The drag coefficients C_D for droplets (isooctane, water, and trichloroethylene) and solid spheres (magnesium and calcium silicide) were found to correlate the Reynolds number Re as given by the empirical expression:

$$C_D = 27/Re^{0.84}$$

for $6 < Re < 400$. When acceleration rates were low, the unsteady-state drag coefficients were in agreement with steady-state values from previous investigations.

From this expression for drag coefficient, an equation relating distance and time was derived for calculating trajectories of solid spheres. In the case of droplets, a graphical method was used to relate droplet diameter to distance when evaporation rates were high. At low rates of evaporation solid-sphere trajectory equations were found applicable.

AMR 10-770

I-7. Ingebo, R. D.

1819. Ingebo, R. D., Vaporization rates and drag coefficients for isooctane sprays in turbulent air streams, *NACA TN* 3265, 39 pp., Oct. 1954.

Drop-size distribution and drop-velocity data were obtained for isooctane sprays in turbulent air streams using a droplet camera developed at the NACA Lewis laboratory. Experimental spray vaporization rates, based on the mean diameter, correlated single-droplet vaporization rates. An empirical expression was derived for isooctane droplet drag coefficients.

AMR 8-1819

I-8. Ingebo, R. D., and H. H. Foster

2186. Ingebo, R. D., and Foster, H. H., Drop-size distribution for cross-current breakup of liquid jets in airstreams, *NACA TN* 4087, 36 pp., Oct. 1957.

Photographing and sampling techniques were combined to obtain drop-size data for ranges of injector, liquid, and airstream variables. The following empirical expressions correlated the ratio of volume-median diameter D_{30} to orifice diameter D_0 with Weber-Reynolds number ratio $D_{30}/D_0 = 3.9\,(We/Re)^{0.25}$ where $We = \sigma/\rho_s D_0 V_s^2$, $Re = D_0 V_s/\nu$, where σ and ν are surface tension and kinematic viscosity, respectively, of the liquid; and V_s and ρ_s are free-stream velocity and density, respectively, of the air. A drop-size distribution equation based on maximum observed drop diameter and Weber-Reynolds number ratio was also derived:

$$dR/dD = 10^4\,(We/Re)^{0.34}\,(D^5/D^6_{max})e^{-22.3\,(We/Re)^{0.1}D/D_{max}}$$

The test installation, comprising a high-speed camera capable of photographing microscopic droplets traveling at high velocity, and the sampling probe, is described and illustrated. A complete sample calculation of mean drop diameter is given. Derivation of dimensional analysis formula is carried out. Reference is made to the work of previous investigators: Rosin-Rammler, Nukiyama-Tanasawa, and Longwell. The atomization of liquid jets was investigated under conditions similar to those in ramjet engines and afterburners.

AMR 11-2186

I-9. (The) Institute of Physics

The Physics of Particle Size Analysis. Brit. Jl. Applied Physics, Suppl. No. 3, Publ. The Institute of Physics (London), 1954, 218 p., numerous fig., tabl., and ref., subject and name index.

Text of 35 papers, with discussions, presented at a conference held on subject, Apr. 6–9, 1954 at University of Nottingham, England, in eight sessions, treating the following main topics: Relative motion of particles and fluids: size separation. Relative motion of particles and fluids: molecular phenomena. Scattering and absorption of light by particles. Particle shape factors. Visual counting and sizing of microscopic particles. Automatized counting and sizing: theory. Automatic counting and sizing: photoelectric machine. General (whiting, thickness of small particles, adhesion, aggregation). In view of the close relationship between small particles and drops and droplets, their physical phenomena, methods of counting and size determination, and other aspects, the papers, with their abstracts are listed individually in this compilation.

deJ II-306

I-10. Irani, R. R., and C. F. Callis

"Particle Size: Measurement, Interpretation, and Application," John Wiley & Sons, New York, 1963.

I-11. Isler, D. A., and D. G. Thornton

1240. Isler, D. A., and Thornton, D. G., Effect of atomization on airplane spray patterns, *Agricultural Engng.* **36**, 9, 600–604, Sept. 1955.

A comparison is made of the effects of three degrees of atomization (300, 150, and 80 microns median diam) on deposit patterns of sprays released from a Stearman airplane flown 50 ft above the ground. Results show that, with upwind tests, coarse atomization resulted in the narrowest swath, least uniform distribution across the swath, and excessively high deposit peaks. Although the fine spray gave a slightly wider and more uniform swath than the medium one, this advantage was cancelled by the higher loss of fine spray. Authors conclude that a spray of medium atomization (150 microns median diam) provides the most efficient swath pattern for forest spraying.

Airplane was rigged with a tubular boom along the span, with nozzles evenly distributed along the boom; liquid was distributed at rate of one gal per acre, over a 132-ft swath, at 80 mph. Atomization was determined by a photographic method. Spray distribution across the swath was determined from spray samples collected on each of two 6-×-6-in. aluminum plates located at 5-ft intervals on a line at right angles to the line of flight.

AMR 11-1240

I-12. Ismaĭlov, I. M., and G. T. Tadzhibaev

"Distillation of Cotton Miscella by Atomization Procedure." I. M. Ismaĭlov and G. T. Tadzhibaev. Masloboĭno-Zhirovaya Prom. 26, No. 5, 40-2 (1960).

CA 54-18990h

I-13. Ito, K.

On Hollow Spindle-Shaped Liquid Jet (in English). K. Ito. Tokyo Imp. U. (Japan), Aero Res. Inst. Rept. No. 81 (1932) Vol. 6, pp. 441–467, 35 fig., 8 plates.

Experiments on low-speed jets of water produced by a large model of a swirl-chamber nozzle. Photographs and measurements of the spray shapes under various conditions. With increasing discharge the shape changes, from a straight jet to hollow spindle or "bottle" with one or more constrictions, then to open funnel shape with edges broken up into filaments and drops.

deJ I-163

I-14. Ivanilov, Iu. P.

A65-27697 #

ASYMPTOTIC BEHAVIOR OF AN AXISYMMETRIC VORTEX JET OF AN IDEAL INCOMPRESSIBLE FLUID [ASIMPTOTIKA OSESIMMETRICHNOI ZAVIKHRENNOI STRUI IDEAL'NOI NESZHIMAEMOI ZHIDKOSTI].

Iu. P. Ivanilov.

Prikladnaia Matematika i Mekhanika, vol. 29, May-June 1965, p. 599-603. 7 refs. In Russian.

Discussion of the behavior of axisymmetric vortex jets at large distances from the nozzle. Several cases in which the appearance of surface waves (expansion and contraction of the jet) is possible are identified and analysed. It is shown that wave modes do not arise in flows for which all eigenvalues are positive, but do arise when negative eigenvalues are present in the spectrum. Solutions that correspond to positive eigenvalues exist only at small distances from the nozzle, while at larger distances the shape of the jet is determined by the negative spectrum of the problem. A finite negative spectrum will not appreciably affect the shape of the jet, causing only sinusoidal changes at the surface. For an infinite negative spectrum, the jet can have a variety of shapes. The analysis leads to a one-parameter family of flows and to an expression relating the flow parameter with the wave amplitude.

A65-27697, 17-12

I-15. Izard, J. A. W.; S. D. Cavers, and J. S. Forsyth

"Production of Liquid Drops by Discontinuous Injection," Chem. Eng. Sci. 18, 467-9 (1963).

J-1. Jaeger, W., and L. F. Weber

"Spraying Apparatus for the Formation of an Electrically Charged Aerosol." Walter Jaeger and Louis F. Weber (to Hydro-Nitro S.A.). Swiss. 273,336, May 1, 1951

CA 46-1896c

J-2. Jarman, R. T.

Rotary Atomizers. R. T. Jarman. Gr. Brit. Colonial Pesticides Res. Unit. Porton Rep. 127, June 1957, 9 p., fig.

Assesses performance of various rotary atomiz tested at Porton as to uniformity of droplet size.

deJ II-235

J-3. Jayaratne, O. W., and B. J. Mason

3824. Jayaratne, O. W., and Mason, B. J., The coalescence and bouncing of water drops at an air/water interface, *Proc. Roy. Soc. London* (A) **280**, 1383, 545–565, Aug. 1964.

A detailed study has been made of the conditions under which uncharged water drops of radius 60 to 200 μm coalesce or rebound at a clean water/air interface. The variable parameters in the system are the drop radius, r, its impact velocity, V_i, and the angle of impact, θ_i; and the dependent parameters are the time of contact, τ, between a rebounding drop and the water surface, the velocity, V_b, and the angle θ_b with which it leaves the surface. All these have been measured. Relations are established between the drop radius and the critical values of V_i and θ_i at which coalescence occurs between uncharged drops and plane or convex water surfaces. Drops impacting at nearly normal incidence remain in contact with the surface for about 1 ms, lose about 95% of their kinetic energy during impact, and rebound with an effective coefficient of restitution of about 0.2. Drops carrying a net charge and drops polarized in an applied electric field coalesce more readily than uncharged drops of the same size and impact velocity. The magnitudes of the critical charges and critical fields required to cause coalescence are determined as functions of V_i, θ_i and drop radius. Typically, drops of radius 150 μm impacting at 100 cm/s coalesce if the charge exceeds about 10^{-4} e.s.u. or if the field exceeds about 100 V/cm.

If the motion of a drop rebounding from a plane water surface is treated as simple harmonic and undamped, one may derive expressions for the depth of the crater, x, and the restoring force, F, at any stage, and also for the time of contact. These yield values that are in reasonable accord with experiment. However, the collision is clearly inelastic, and a second solution is obtained when F is assumed to be proportional, not only to the displacement, x, but to x/t. This leads to a slightly different expression for the time of contact and to a calculated energy loss of 84% compared with the measured value of 95%.

If the drop is to coalesce with the water surface, it must first expel and rupture the intervening air film. Treating the undersurface of the drop as a flattened circular disk, an expression is determined for the minimum thickness, δ, achieved by the film during the period of contact, in terms of V_i, θ_i and the drop radius r. This predicts values of $\delta \sim 0.1$ μm below which fusion may well take place under the influence of van der Waals forces. Several features of the observed relations between V_i, θ_i and r are accounted for by this simplified theory, but the behavior of drops impacting at nearly glancing incidence, and of relatively large, energetic drops impacting nearly normally is not. In the latter case, the observed distortion of the drop is thought to play an important role in permitting more rapid thinning of the air film and, in the case of charged and polarized drops, by producing intense local electric fields that may cause the final rupture.

AMR 18-3824

J-4. Jenkins, D. C.

"Note on the Possibility of Raindrops Being Shattered by the Air Disturbances Caused by a Moving Body," Roy. Aircraft Estab. Tech. Note, Mech. Eng. 239, Oct. 1957.

J-5. Jenkins, D. C., J. D. Booker, and J. W. Sweed

"An Experimental Method for the Study of the Impact Between a Liquid Drop and a Surface Moving at High Speed," Royal Aircraft Establishment, London Aeronautical Research Council, R & M No. 3203, 1961.

J-6. Joeck, T. D.

"Method of Atomizing by Supersonic Sound Vibrations," U.S. Patent 2,532,554, Dec. 5, 1950.

J-7. Johnson, C.

2363? PRODUCTION OF LIQUID DROPS.
C.Johnson.
Nature (GB), Vol. 197, 1002-3 (March 16, 1963).

A photographic study of drop formation from a hypodermic steel needle when the needle is at a smooth potential of 4 kV. The application of this potential decreased the size of drops to such an extent that to the naked eye they appeared as a continuous jet, the frequency of drops being increased from 3-4/sec to 300/sec. Qualitative explanation of photographs suggests that electrostatic forces opposing surface tension at surfaces of high radius of curvature weakens the area, causing increased flow, thus creating a sharp nosed filament, necking and subsequent small drop formation.

PA 66-23857

J-8. Jones, J. B., J. L. Straughn, and W. B. Tarpley, Jr.

"Aerosolization Unit." James B. Jones, John L. Straughn, and William B. Tarpley, Jr. (to Aeroprojects, Inc.). U.S. 2,998,391, Aug. 29, 1961, Appl. May 24, 1957; 7 pp.

CA 57-16364h

J-9. Joyce, J. R.

Methods of Atomizing Liquid Fuels. J. R. Joyce (Shell Research, Ltd. London). Jl. Inst. of Petroleum, Vol. 39, No. 350 (Feb. 1953), pp. 57–81, 14 fig., 4 ref. Also in Jl. Inst. Fuel. Vol. 26 (1953) p. 200.

After brief discussion of purpose and significance of liquid fuel atomization, and a detailed consideration of the physical mechanism of the process, a general description, with schematic drawings, is given of the main types (low-pressure air, medium-pressure air, high-pressure air atomizers, drooling or weir type, "scent-spray" air or steam atomisers, mechanical (rotary) atomizers with cup or disc, swirl-type atomizers) of practical atomizers and oil burners, with comments on the operational requirements and characteristic features of each. Considerations affecting the choice of atomizers are reviewed, and the heat imput, energy imput, and the equivalent cost (about 4 shilling per ton of oil) of atomization is briefly discussed. Features required in a good atomizer are listed, followed by a reference to requirements in testing, including examination of spray pattern symmetry, and drop size distribution (illustrated with photographs). Main physical factors in burners, which affect the quality of atomization are mentioned. Only fuel factor affecting atomization is the viscosity; advantage of preheating heavy fuels is emphasised. It is pointed out that good atomization is only one factor in efficient oil burning; properly prepared and directed air supply is also important.

deJ I-171

J-10. Joyce, J. R.

The Atomization of Liquid Fuels for Combustion. J. R. Joyce (Shell Petroleum Co., Ltd.). Jl. Inst. Fuel (Engl.) Vol. 22 (1949), pp. 150–156, 19 fig.

After considering the mechanism, and basic purpose of atomization, and a description of the principal types of atomizers (air- or steam-atomizing nozzles, rotary cup, swirling-atomizer), the pressure-jet atomizer is described in detail, calling attention to faults in design and manufacture. Liquid-fuel combustion is a vapor-phase process, the function of atomization being primarily that of preparing less volatile fuels for vaporization. Importance of the smaller droplets is emphasized and an account is given of the process of combustion. After a general description of the molten wax method of particle-size measurement and the determination of the characteristics of a spray in terms of n and x in the Rosin-Rammler expression $R = 100e^{-(x/\bar{x})}$, reference is made to the various factors affecting the quality of atomization, including fuel preheating.

deJ I-171

J-11. Joyce, J. R.

Fuel Atomizers for Gas Turbines. J. R. Joyce. Shell Petroleum Co. Ltd., London, Techn. Rept. No. ICT/15 (1947), 59 p., 36 fig.

Constructional features of various forms of the single-chamber centrifugal atomizer of which about 24 designs are shown; their fundamental similarity in effecting atomization, their performance characteristics, limitations, and faults in design and manufacture. Evolution of the "wide-range" atomizers in England is traced and many types are described. Some actual American and German, and some proposed designs are shown. Basic requirements for atomizers for aircraft gas turbines are reviewed (simple design, equal performance of all atomizers fitted to an engine, uniform distribution of fuel in the combustion space, fine atomization over the entire operating range); testing methods are discussed briefly.

deJ I-171

J-12. Joyce, J. R.

The Wax Method of Spray Particle Size Measurement. J. R. Joyce. Shell Petroleum Co. Ltd., London, Techn. Rept. No. LCT/7 (1946), 48 p., 20 fig., 5 ref.

Attempts to freeze kerosene spray particles in flight; in the vapor of liquid nitrogen the method was abandoned as impractical. Instead the spraying of molten paraffin wax was adopted. The drops which solidify in flight were originally measured and counted under the microscope, later separated in size groups by sieving. As it was found that at least 5000 drops are required for a satisfactory averaging, the sieving method gave not only faster but also more accurate results. Total discharge is collected by a large funnel under the spray with the funnel being wetted by a stream of water. Description of test apparatus and procedure development. Discussion of errors due to hollow wax beads and particle agglomeration. Results suitable for plotting according to Rosin-Rammler formula except for very fine sprays. Sieve gauze of 400 per inch mesh, of 0.001 Monel wire, giving interstices of 0.0015 in. sq. is the finest available at present. Typical data presented.

deJ I-171

K-1. Kawada, M.

Experiments on Atomizer with Impinging Jets (in Japanese). Masaaki Kawada (Dep. Mech. Engng., Univ. Tokyo, Japan). Proc. Tokyo Inst. Tech., Vol. 8, No. 4, Apr. 1939, pp. 169–177, 9 fig.

Spark photographs were taken of impinging water jets at low pressure, under various conditions. Scheme of experimental set up is shown. Used orifice sizes of 0.735 to 1.5 mm. dia, impingement angles of 180 to 60 deg., and water pressure about 50 to 500 cm. water column. The two impinging jets merge into a thin film; particles separate from the edge of the film in an approx. regular way; spread of film is almost proportional to the jet pressure up to a certain pressure, above which the film begins to vibrate and the spread shortens; a larger dia. jet gives longer spreading length. Average particle size vs. water pressure is shown in graph.

deJ II-245

K-2. Keats, J. L.

"Aerosols." John Lewis Keats (to E. I. du Pont de Nemours & Co.). U.S. 2,980,582, Apr. 18, 1961.

CA 55-25100f

K-3. Keller, J. B., and I. Kolodner

3798. Keller, J. B., and Kolodner, I., Instability of liquid surfaces and the formation of drops, *J. appl. Phys.* **25**, 918–921, 1954.

The theory of Taylor instability [G. I. Taylor, *Proc. roy. Soc. Lond.* (*A*) **201**, 192–196, 1950; see AMR **4**, Rev. 757; R. Bellman and R. H. Pennington, *Quart. appl. Math.* **12**, 151–162, 1954] is extended to the case of a liquid layer of thickness h between two parallel free boundaries (e.g., of gas) at different pressure, p_1, p_2. The most unstable perturbation mode is then calculated, with surface tension T included, and used to predict a mean drop radius r under breakup. The final formula is $r = [9\pi Th^2/2|p_1 - p_2|]^{1/3}$; no comparisons with experimental data are given.

AMR 8-3798

K-4. Keller, J. B., and M. L. Weitz

1920. Keller, J. B., and Weitz, M. L., A theory of thin jets (in English), 9th Congrès Intern. Mécan. Appl., Univ. Bruxelles 1957; 2, 316–323.

Irrotational flow under the influence of gravity is studied for a liquid jet whose characteristic vertical thickness h is small compared with the horizontal distance a traversed by the flow. By extension of method developed for shallow water theory [AMR 2 (1949), Rev. 1029] authors indicate how solutions may be obtained as series in powers of (h/a). Method is demonstrated to zero-order approximation for unsteady jets, to first-order approximation for unsteady jets, and, with a slight modification of the method, to zero-order approximation with pressure variation to first order) for unsteady flow over a rigid surface, e.g. a spillway. Misprints make the paper difficult reading.

AMR 12-1920

K-5. Kerker, M., A. L. Cox, and M. D. Schoenberg

"Maximum Particle Sizes in Polydispersed Aerosols," J. Colloid Sci. 10, 413-27 (1955).

The size distributions of mercury and sulfur aerosols have been investigated by a light scattering-settling technique and the results compared with direct electron microscope observations. For the larger size aerosols the maximum size obtained by light scattering agrees with the electron microscope maximum but the distribution curves differ. For smaller aerosols (maximum by electron microscope less than 0.1 μ) the light scattering shows no maximum size. These discrepancies are attributed to convection and coagulation. The liquid nature of sulfur aerosols is demonstrated by photomicrography and a new technique of preparing them for the electron microscope is described.

Author

K-6. Kethley, T. W., et al.

"Air-borne Microörganisms as Analytical Tools in Aerosol Studies." T. W. Kethley, Clyde Orr, Jr., E. L. Fincher, and J. M. DallaValle (Georgia Inst. of Technol., Atlanta). J. Air Pollution Control Assoc. 7, 16-20 (1957).

CA 51-12391a

K-7. Khokhlov, S. F.

"Hydrodynamics and Mass-Transfer in a Centrifugal Column." S. F. Khokhlov. Khim. Mashinostroenie 1960. No. 1, 24-7.

CA 54-21884b

K-8. Kim, K. Y.

"Drop-Size Distributions from Pneumatic Atomizers." Keun Y. Kim (Univ. of Wisconsin, Madison). Univ. Microfilms (Ann Arbor, Mich.), L. C. Card No. Mic 59-2770, 296 pp.; Dissertation Abstr. 20, 612-13 (1959).

CA 53-19469h

K-9. Kimoshita, M., and K. Uchiyama

On the Size of Fog Droplets. M. Kinoshita and K. Uchiyama. Tokyo Imp. U. (Japan) Scientific Papers. Inst. Phys. and Chem. Res. No. 391 (1932).

Fog-laden air from a small jet impinges onto a slide coated with film of vaseline.

deJ I-176

K-10. Kirchhoff, G.

Zur Theorie freier Flüssigkeitsstrahlen (On the Theory of free liquid jets). G. Kirchhoff (Univ. Heidelberg, Germ.). Crelle's Jl. f. d. reine u. angew. Mathematik (Berlin), Vol. 70, No. 4, 1869, pp. 289–298, 5 fig.

Cited in WADELL 1934. Refers to HELMHOLTZ 1868 which gives theoretical calculation of the shape of a free liquid jet, for one particular case. Generalizes Helmholtz's method, and obtains, by hydrodynamic calculations, the jet shape for several cases: from a sharpedged orifice; from a reverse efflux tube; for impingement against a disc, perpendicularly and at an angle. Treatment is purely by mathematical analysis.

deJ II-249

K-11. Kivnick, A.

"The Coalescence of Droplets in a Turbulent Jet," Army Chem. Corps Contract No. DA 18-64-CML-445, ONR Contract No. N6-ori-71 T.O.XI, Technical Report No. CML-4, August 1, 1952.

K-12. Klein, E.

Messung und Darstellung der Tropfengrößenverteilung in einem Zerstäubungsstrahl (Measurement and representation of drop-size distribution in a spray). Eugen Klein (Deutsche Versuchsanstalt f. Luftfahrt, e.V., Institut f. Turbulenzforschung, Berlin-Charlottenburg). Brennstoff-Wärme-Kraft, Vol. 10, No. 6 (June 1958), pp. 263–269, 13 fig., 6 ref.; discussion by several scientists. Further discussion in pp. 269–270, with 3 ref.

Conditions for obtaining a representative sample for evaluating drop-size distribution in a spray are not fulfilled even in direct measuring methods. Improved results can be obtained by the immersion method, by immediately centrifuging all drops contained in a sector of the spray, which is cut off by a quickshutting spray diverter. A representation of the measured drop-size distribution is proposed, by two parameters of a normal distribution curve. These two parameters give a definition of the change of distribution under changing operating conditions. An air-atomizing nozzle was used. Several designs of collecting sondes are described, for catching a sample of the droplets in some non-miscible liquid, and rapidly freezing and subsequently centrifuging it. Another method uses a stream of high pressure air stream for diverting the spray from its original direction, except for a short time interval of about 0.01 sec. during which it is caught in the test centrifuge. Equipment is illustrated, operation described, error sources discussed. Representation by a single parameter (Sauter-Mean-Diameter), and by two parameters is discussed. Other discussers call attention to the possibility of using three, four, and five parameters, whereby a closer approximation to the experimentally obtained curve can be obtained at a cost of increased complication of the furmulas.

deJ I-177

J-13. Kleinschmidt, R. V.

Theory of Dispersion of Liquid Droplets. R. V. Kleinschmidt. Chem. Engrs. Handbook (J. H. Perry, Ed.). McGraw-Hill, New York, 3rd Ed. (1950), pp. 1169–1170.

Basic mechanism of drop formation consists in drawing out the liquid into a slender filament. As direct formation of liquid streams thin enough to produce fine sprays is not practicable, secondary actions are resorted to: (1) Impingement of high velocity turbulent air or steam jets on the liquid surface, (2) Spreading out the liquid into a thin sheet. Energy required fo form a liquid into drops, and dispersion, are discussed.

deJ I-177

J-14. Kling, R.

Kling, R.
EXPERIMENTAL RESEARCH ON THE COMBUSTION APPEARANCE IN AN ANNULAR SECTOR OF A TURBINE-JET PROPULSIVE-UNIT (Experimentalle Ontersuchung der Verbrennung ser Scheinungen in Einem Ringbunnkammersektor Turbinenstrahltriebnerks). [1961] 13p. (15 figs. 7 tables omitted).
Order from SLA $1.60 62-10050

Trans. of Zeitschrift für Flugwissenschaften (West Germany) 1960, v. 8, no. 12, p. 345-352.

DESCRIPTORS: Turbines, Jets, *Jet propulsion, *Combustion chambers, Combustion, Experimental data, Microphotography, High speed photography, Photography, Fuels, Atomization, Distribution.

T7-655

K-15. Kling, R.

"The Atomization of Liquid Fuels by Centrifugal Injection," Recherche Aéronaut, 1958, No. 66, 13-21

La pulvérisation par coupelle tournante est utilisée depuis de nombreuses années pour l'alimentation de foyers de chaudières en combustibles liquides.

Un dispositif un peu différent est utilisé par la Société Turboméca pour l'injection du carburant dans la chambre de combustion de ses turboréacteurs.

Il consiste essentiellement en une roue percée de canaux situés dans des plans passant par l'axe de rotation et alimentés en carburant par une tuyauterie axiale.

Cette roue est montée sur l'arbre de la turbine. Sous l'action de la force centrifuge, le liquide se trouve accéléré vers l'extérieur à travers les canaux. Il est ensuite projeté à grande vitesse dans la chambre de combustion où il se pulvérise.

La structure des jets liquides produits, ainsi que celle du brouillard de carburant finalement obtenu, ont été étudiées en fonction des paramètres fondamentaux : vitesse de rotation et débit de carburant.

Author

K-16. Kling, R.

2756. Kling, R., Application of microphotography of fuel sprays to the study of jet engine combustion chambers (in French), Paper presented at Colloquium on flow and combustion, Freudenstadt, 25 pp. + 11 figs. + 15 ref., 1957.

The spray produced by Duplex-type nozzles in the combustion chamber of a Nene engine was studied by means of photomicrographs. Spark illumination produced by a Fruengel-strobolamp (made by Dr. F. Fruengel, G. m. b. H., Hamburg-Rissen) was used, using two sparks with a time interval of 100 microseconds. The sparks were initiated by the contactor of a robot camera, the shutter of which had an open interval of 1/25 sec. From the two successive pictures of the same droplet the velocity of droplet movement and its direction could be determined. The adaptation of the combustion chamber for this investigation by fitting it with quartz windows, the optical system and the mounting of the camera are described and illustrated in detail. The pictures taken were evaluated for Sauter mean diameter, and for a qualitative indication of the chamber turbulence. Viewing windows were provided at three distances from the injector, thereby it was made possible to study the change of the spray characteristics as the spray progresses along the axis of the combustion chamber.

AMR 11-2756

K-17. Kling, R., G. Chevaierias, and A. Maman

"L'injection par Jets Concourants Dans les Chambres de Combustion de Fusses a Liquides," Office National d'Edudes et de Recherches Aeronautiques, 9 eme Congres International de Mecanique Appliquee; Bruxelles, Sept. 1956.

K-18. Kling, R., and R. Leboeuf

2757. Kling, R., and Leboeuf, R., An ultra-rapid microphotographic method and its application to the study of formation and development of combustible sprays (in French), Actes du Deuxieme Congres Internationale Photographie et Cinematographie Ultra-Rapide, 424–431 + 13 figs. + 5 ref., 1956.

Microphotography technique for studying sprays has to satisfy three main requirements: (1) a light source small enough and light duration short enough to produce an unblurred picture of the smallest droplet in motion; (2) an optical system to provide a sufficient distance between the lens and the spray to make possible the spray study without or with combustion; (3) it should be possible to take a large number of pictures in a short time interval for a study of motion and spray development, and of drop-size distribution. The apparatus developed by the authors comprises a pinpoint light source by a spark occurring between two tungsten electrodes in argon at 6 atm pressure, generated by the discharge of a 0.04 microfarad condenser charged to 6 kilovolts; the duration of flash is about 150 mμ with a 1:1 magnification; this provides a visibility of a droplet of about 8 microns. The field of view is about 4 ... and the photographic frame is 24 x 24 mm. The pictures ... examined under a microscope; a droplet of 10 microns diam appears as a spot of 1-mm diam. With this equipment, two impinging liquid jets, the resulting liquid sheet, and its breakup into filaments and droplets were investigated. Photos of the spray are shown; graphs of droplet-size distribution in terms of total surface versus distance from impact point of the two jets are given.

AMR 11-2757

K-19. Klumb, H.

Neues Verfahren zur Erzeugung und zur meßtechnischen Definierung hochdisperser Aerosole (New method for the production and for the metrological definition of highly dispersed aerosols). Hans Klumb (Univ. Mainz). Schwebstofftechnische Arbeitstagung 1954. Publ. by Phys. Inst. Johannes-Gutenberg-Univ. Mainz, Germany), pp. 2–4, 2 fig.

Methods for producing highly dispersed aerosols: Electrostatic atomization; Atomization by compressed air; Centrifugal atomization; Chemical and thermal methods.

New method of measurement: deposition by centrifugal force on glass slides for ultramicroscopic evaluation (SCHWENDEMANN) on a transparent plastic film. Spectrum of size-distribution is directly visible; the method is termed: Aerosol-Spectrometry.

deJ I-180

K-20. Kohler, H.

1349. Kohler, H., Some thermodynamic formulas and their interpretation, *Ark. Geofys.* **2**, 21, 453–470, Mar. 1956.

This highly theoretical and mathematical paper concerns itself with the rigorous derivation, from basic thermodynamic principles, of the surface tension as a function of the radius of curvature of the "surface of tension." Reference is taken to Willard Gibbs' treatment, based on the concept of thermodynamic potential, and the conditions of equilibrium between the pressure within a droplet and the surrounding vapor pressure are investigated. The paper uses also molecular concepts, and assumes that the droplet grows in a vapor state in which no droplet yet exists, to a size large enough to be in equilibrium with the vapor. In this process the droplet grows from a few molecules to a droplet with a large number of molecules. This view implies that at the beginning of the process the concept of surface tension, as such, has no meaning but it can be regarded as a mathematical equivalent to the intermolecular forces, and therefore surface tension must be defined in terms of statistical thermodynamics.

This profound treatment of surface tension surpasses often the field of engineering, and even that of physics, and transcends into the realm of philosophy.

AMR 11-1349

K-21. Kolmogorov, A. N.

Kolmogorov, A. N.
THE BREAK-UP OF DROPLETS IN A TURBULENT STREAM. tr. by E. R. Hope. June 56 [6]p. 2 refs.
T 210 R; M 1556; AD-145 405.
Order from LC or SLA mi$1.80, ph$1.80 60-23010

Trans. of Akad[emiya] Nauk [SSSR]. Dok[lady] 1949, v. 66, no. 5, p. 825-828.
Another translation is available from LC or SLA mi$1.80, ph$1.80 as 60-17228, DSIR LLU M.1407 [1960] 4p.

An analysis shows that if there is introduced into a turbulent stream, another liquid having the same density, the same kinematic viscosity, and a surface tension (σ) equal to zero at the interface with the first liquid, then the liquid does not break up into droplets but is deformed into an ever-finer twisting and branching filament. When mixing occurs the filament breaks up into droplets, which become smaller up to the point where the velocity difference (v_d) that acts to shatter the droplets is no longer able to overcome σ. What happens to the droplets of diameter d depends only on the dimensionless ratios d/λ_0, ν'/ν, and the Weber number $We_d = \sigma/v_d^2 d$, where λ_0 represents the internal turbulence scale, and ν' and ν are the kinematic viscosities of the introduced stream and the original liquid respectively. When $d \approx \lambda_0$ the number of the dimensionless characteristics of the process cannot be reduced. When $d \ll \lambda_0$ the viscosity forces outweigh the inertia forces and the process depends only upon We_d and ν'/ν. When $d \gg \lambda_0$ the viscosities of both liquids may be neglected unless $\nu' \gg \nu$, in which case the process depends only upon We_d.

T4-662

K-22. Kolodner, I. I.

Instability of Liquid Surfaces and the Formation of Drops. Part II: A Refined Theory. Ignace I. Kolodner (New York Univ., Inst. Math. Sciences, New York, N.Y.). Rep. IMM-NYU-251, June 1956, 28 p., 12 fig., 7 ref.

Previous study: KELLER and KOLODNER 1954, treated the problem of accelerated liquid sheets assuming that the sheet is thin. Present investigation extends the treatment to sheets which are not thin, and examines whether the previously obtained relationships and formulas are valid for this case. Considers the free boundary problem in which one surface is kept rigid, and the other has a sinusoidal profile. Gives mathematical formulation to the problem; then deals with the instability theory in first-order approximation, as applied to the case of surfaces having one-dimensional profile. Presents a solution worked out explicitly to terms of third order. A chapter is devoted to discussion of results in terms of various chosen values for the significant parameters. Cited: BELLMAN and PENNINGTON 1952; LAYZER 1952; PENNINGTON et al. 1953; TAYLOR 1950.

deJ II-256

K-23. Kolodner, I. I.

The Formation and Subsequent Behavior of Aerosols. Progress Report, Jan. 1954. Ignace I. Kolodner (New York Univ., Inst. Math. Sciences, New York, N.Y.). Rep. IMM-NYU-204, 35 p., 5 fig., 40 ref.

Reviews work on subject during period Nov. 1951 to Dec. 1953. Part I discusses the formation of aerosols based on hydrodynamic theory, and reviews previous researches (breakup of steady jets, and of liquid layers). Part II treats decay of drops by evaporation, and growth by condensation (treats a single drop, first approximately then more rigorously then treats a collection of drops). Plans to study later the collision and coalescence of drops produced by turbulence or falling. Bibliography includes early literature from about 1833 (SAVART 1833, BUFF 1857, PLATEAU 1873).

deJ II-255

K-24. Kolodner, I. I.

On Jets Produced by Conical Nozzles. Ignace I. Kolodner (New York Univ. Inst. Math. Sciences, New York, N.Y.). Rep. IMM-NYU-209, May 1954, 27 p. 6 fig.

Reviews qualitatively the formation of a liquid jet from a conical nozzle, which has first a closed hollow tulip shape, oscillating about its equilibrium position; if it is vented, i.e., the inside communicates with the outside, thus the pressure is equalized, then no oscillation occurs. Present paper is a quantitative study of this phenomenon, under the assumption of thin jet theory. In first section the problem is given a mathematical formulation, considering the general case of unsteady motion. Second section deals with the equilibrium jet, neglecting gravity effects, but estimating corrections for it. Third section discusses results of former section and compares them with experimental data. Fourth section contains approximate treatment of unsteady jet. Refers to HODGKINSON 1950.

deJ II-255

K-25. Komabayasi, M., T. Gonda, and K. Isono

"Life Time of Water Drops before Breaking and Size Distribution of Fragment Droplets," J. Meteorl. Soc. Japan 42, No. 2, 330-40 (Oct. 1964).

K-26. Korotkikh, G. I.

Korotkikh, G. I.
UTILIZATION OF AEROSOL APPARATUS (Primenéniye Aerozol'noy Apparatury). 29 July 60, 7p. (2 figs. omitted). Trans. A-1176.
Order from LC or SLA mi$1.80, ph$1.80 60-23152

Trans. of Zashchita Rastenii [ot Vrediteley i Bolezney] (USSR) 1960, v. 5, no. 5, p. 43-45.

Troubleshooting procedures are given for operators of the AG-L6 aerosol generators issued by the Kolomensk Repair Factory.

T4-368

K-27. Korotkikh, G. I.

Korotkikh, G. I.
AEROSOL GENERATORS (Aerozol'nyye Generatory). 7 July 60, 4p. Trans. V-1572.
Order from LC or SLA mi$1.80, ph$1.80 60-23168

Trans. of Zashchita Rastenii [ot Vrediteley i Bolezney] (USSR) 1957, v. 2, no. 5, p. 50-51.

Descriptions are given of the manual pulsating generator RAG-1 made in Czechoslovakia and the insecticidal electric lamp "Insecta" used in Austria, Sweden, France, and other countries.

T4-368

K-28. Kottler, F.

The Goodness of Fit and the Distribution of Particle Sizes. F. Kottler. Jl. Franklin Inst., Part I: Vol. 251 (1951), No. 5, pp. 499–514; Part II: Vol. 251 (1951), No. 6, pp. 617–641, 41 p., 8 fig., 15 ref.

Continuation and further development of KOTTLER 1950. Presents an algebraic method using the Chi-Square Minimum Principle (instead of the usual principle of least squares) for the analysis of particle size distribution in a photographic emulsion. It characterizes the photographic emulsion by two parameters: the first "a", related to the time of crystal growth, and the second, "b", which is inversely proportional to the velocity constant of growth. This is an advanced study; it compares the graphical and algebraic analyses, favoring the latter.

deJ I-184

K-29. Kottler, F.

The Distribution of Particle Sizes. F. Kottler (Eastman Kodak Co., Rochester, N.Y.). Jl. Franklin Inst., Vol. 250 (1950), Part I (Oct.), pp. 339–356, Part II (Nov.) pp. 419–441, 8 fig., 42 ref.

Critical review of previous literature on particle size distribution. The distribution law should be connected with the law of crystal growth for which the exponential law is chosen. In the application of the Logarithmico-Normal law to experimental data, graphical analysis is generally used. Suggests that this graphical method should be replaced by an algebraic one.

deJ I-184

K-30. Kraemer, H. F., and W. E. Ranz

15509 Homopolar Electrification of Aerosols. H. F. Kraemer and W. E. Ranz. *University of Illinois, Engineering Experiment Station Technical Report for U. S. Atomic Energy Commission, Contract No.* AT(30-3)-28, Sept. 1952, 39 p. (TI 10 Contin.)

Design and construction of a device which would produce an aerosol with particles all of the same size and bearing the same electric charge. Derivation of theoretical equations which explain the operation of the equipment. Method of measuring the charges on the aerosol particles and of measuring the charges on the aerosol particles and of detecting any nonuniformity in size or charge.

BMI 5-15509

K-31. Kranz, J.

Über der Einfluß der Oberflächenspannung auf die Tropfengröße bei der pneumatischen Verneblung (Influence of surface tension on drop size, in air atomization). Jakob Kranz (Univ. München, München, Germ.). Z. f. Aerosol-Forschung und -Therapie, Vol. 2, No. 2, Apr. 1953, pp. 295-296.

With a medical inhalator atomizer two liquids were atomized under the same conditions: distilled water (surf. tension 72.6) and a 0.1% aqueous solution of sodium aurisulfat (surf. tension 27.4 erg cm^{-2}), and their drop-size spectra determined. Droplets of distilled water were in the range below 12 micron, while those of the liquid of reduced surface tension were below 6 micron; percentage of drops below 5 micron (which is medically the most efficaceous) was increased from 27 to 90 percent.

deJ II-257

K-32. Kruse, C. W., A. D. Hess, and G. F. Ludvik

The Performance of Liquid Spray Nozzles for Aircraft Insecticide Application. C. W. Kruse, A. D. Hess, and G. F. Ludvik (T.V.A., Wilson Dam, Ala.). Jl. Nat. Malaria Soc., Vol. 8 (1949), No. 4, pp. 312-334, 8 fig., 8 ref.

A surface-volume mean diameter D_o introduced by Nukiyama and Tanasawa expresses spray composition spectra more accurately than the older mass-median diameter concept. Detailed description of application is given. A study of the effects of pressure and physical properties of liquids on particle-size spectrum of sprays showed that viscosity is of considerable importance. D_o of spray spectrum appears to vary directly with functions of viscosity and surface tension and inversely with functions of liquid velocity and specific gravity. An empirical equation expressing these relations is presented. Supports theory of Nukiyama and Tanasawa that breakup of liquids after leaving an orifice is due to interaction of liquid with air and is proportional to velocity difference between the two. Data obtained on spray spectra under pressures between 20 and 100 psi as influenced by speeds between zero and 180 mph with nozzle discharging forward and backward. (Example: with a given nozzle the D_o was 164 micron in the forward, 290 micron in the backward, and 188 micron in the downward orientation.)

deJ I-186

K-33. Kuehn, R.

Über die Zerstäubung flüssiger Brennstoffe (Atomization of liquid fuels). R. Kuehn. Motorwagen (Germ.) Vol. 27 (1924), No. 19, 20, 28, 29, 33, 34; Vol. 28 (1925), No. 2 and 4. Translation: NACA, TM 329, 330, 331 (1925), 129 p., 31 fig.

A small portion of a spray from a fuel injection nozzle was caught on smoked glass and the drop sizes measured by counting the number of drops and weighing the weight increment of the plate. Survey of previous theories and experiments relating to the formation of drops; application of dimensional analysis to the laws of atomization and dispertion. Liquid pressures up to 570 psi were used; air pressure in chamber was atmospheric.

deJ I-187

K-34. Kuharjev, M. N.

Issledovania raspilivania topliva primenitelno k bistrohodnim dizeljam (Investigation of fuel atomization suitable for high-speed Diesel engines). M. N. Kuharjev (Hauchno-Avtomotornij Institut, NAMI, Moskva). Trudi NAMI, Vol. 87, 1959, pp. 3-36, 35 fig., 6 tabl., 14 ref.

Describes experimental equipment, and photographing and measuring methods for fineness and distribution of fuel spray. Used pintle-type nozzles. Investigated the effect of: air pressure and fuel viscosity, size of droplets in the various phases of injection, amount of fuel per injection, the r.p.m., limiting the motion of the needle valve, injection pressure; fuel temperature, and fluctuation of injection pressure. Made experiments with unit injectors (GMC type). Presents equation for mean droplet diameter as a function of nozzle orifice and Weber Number.

deJ II-259

K-35. Kuhn, W.

Spontane Aufteilung von Flüssigkeitszylindern in kleine Kugeln (Spontaneous breaking up of liquid cylinders in small spheres). Werner Kuhn (Phys.-chem. Inst., Univ. Basel, Switzerland). Kolloid-Z., Vol. 132, No. 1-2 (1953), pp. 84-99, 4 fig., 3 ref.

A long, extended liquid cylinder can, under the influence of surface tension, not only contract into one sphere, but can break up spontaneously into a series of small spheres. It is shown that an extended circular cylinder is unstable for small constrictions or swellings of its surface if the axial extent of disturbance is greater than the cylinder radius; but it is stable when the extent of the disturbance is smaller than the cylinder radius. The breakup into a multiplicity of spheres is effected by the heat interchange which produces initial constrictions--without any promoting or resisting effect by the surface tension; these initial constrictions are subsequently completed by the surface forces. The time is estimated which is necessary for generating, by the Brownian forces and against the viscous resistance of the liquid cylinder, an initial constriction of sufficient length and depth, that through the interfacial forces, in a further time interval, a complete cut off results. The sum of the two time elements: that for generating the initial constrictions plus that for completing same, equals the time within which a spontaneous breakup of the cylinder in smaller particles must take place. This is represented by an equation and by a tabulation, for the case that besides the initial constriction by the Brownian movement also other simultaneously occurring mechanisms exert an influence. The total time thus determined represents the upper limit for the life of the cylinder, inasmuch as with other additional disturbances a more rapid breakup of the cylinder into drops can be expected. According to these concepts also macroscopic cylinders break up into a series of small spheres in finite times, as a consequence of the Brownian movement, the effect of which can be observed otherwise only in a microscope or an ultramicroscope.

deJ I-187

K-36. Kuhn, W., H. Majer, and F. Burkhardt

3737. Kuhn, W., Majer, H., and Burkhardt, F., Velocity of spontaneous breaking up of liquid cylinders into small spheres (in German), Z. *Elektrochemie* 63, 1, 70-74, 1959.

Previous work [Kuhn, "Spontaneous breakup of liquid cylinders into small spheres," *Kolloid*-Z. 132, 1-2, 84-99, 1953] showed that a stretched liquid cylinder, acted upon by surface tension, can contract into one single sphere, and also can break up spontaneously into a number of smaller spheres. The breakup of the cylinder into spheres is first initiated by heat effect, then the initial constrictions are completed into total separation by interfacial tension. The times of these two periods have been calculated, and in present research have also been measured experimentally.

A filament of oligostyrol has been stretched out in a water-methylcellulose solution which had the same density as the filament (to eliminate the force of gravity). In the experiment, a thin layer of oligostyrol was poured into a glass cup where it settled on the bottom; then over it a 16% water solution of methylcellulose was poured. Dipping the tip of a glass rod into the oligostyrol and pulling it upward, a filament of about 10-cm length was produced; then the glass rod was fastened into a fixed position. From this instant onward, the time was measured for the filament, fastened at both ends, to break into droplets. This took long enough for the thickness of the filament to be measured by means of a telescope fitted with an ocular micrometer.

The experiments substantiated the proportionality of the breakup time with the diameter of the filament, but the time was far less than the value calculated on the assumption of a perfectly smooth and round filament. An attempt is made to explain this discrepancy by (1) the effect of tension and compression instead of purely Poiseuille flow, and (2) energy fluctuations based on the Maxwell-Boltzmann principle; but these account for only a small part of the discrepancy.

AMR 13-3737

K-37. Kulagin, L. V.

4295. Kulagin, L. V., Determination of the angle of a torque of fuel with escape of fuel from a centrifugal nozzle (in Russian), *Vestnik Vses. Nauki In-ta Zh-d. Transp.* no. 2, 40-44, 1959; *Ref. Zh. Mekh.* no. 3, 1960, Rev. 3213.

A short description is given of the principles and scheme of work of a centrifugal jet. Analysis is made of formulas prepared by various authors for calculating the radical angle of a jet from a centrifugal nozzle. It is shown that in these formulas no account is taken of the reaction of the streams shooting out to various distances from the axis of the nozzle. A formula is offered for determining the radical angle of the jet with a more careful allowance for the effect of the separate streams of liquid on the resulting angle of the jet. In order to test the formula, tests were made with centrifugal jets with varying data and permitting variation of the geometrical characteristics of the nozzle from 0.8 to 7. The angles of the jet were determined by photography. The tests confirmed the correctness of the proposed adjusted formula for calculating the angle of the jet.

AMR 16-4295

K-38. Kurabayasi, T.

3052. Kurabayasi, T., Atomization of liquid by means of a rotating nozzle (effects of physical properties of liquid on droplet sizes), *Bull. JSME* 4, 15, 539-546, Aug. 1961.

This is a further report on a continuing research on liquid atomization by rotating nozzle, former reports on which were reviewed as AMR 14(1961), Revs. 3900 and 3901. In previous experiments water was used as a sprayed liquid; in present research the effects of viscosity and of surface tension are explored by using mixtures of glycerine and water (viscosity range 10 to 130 millipoises) and of ethyl alcohol and water (surface tension range 30 to 74 dyne/cm). At low rotating speeds, increasing the viscosity caused a decrease of mean droplet diameter; but at full spraying speed the effect of viscosity is small. Decreasing the surface tension reduced the droplet diameter in any of the modes of disintegration. At low rotating speeds the size distribution exhibited two peaks; with increasing speeds the two peaks came closer, and, finally, at full spraying speeds they merged into one. Author derives empirical formulas for the Sauter mean diameter, and for the frequency curve for the fully developed spray. The parameters are determined for a representation of drop-size distribution, using the Nukiyama-Tanasawa exponential function.

This report, in conjunction with the previous two, is a competent addition to spray literature, and it is reasonable to expect that further reports will be made as the research is continued. It is to be hoped that, after the series is completed, a unified summary and comprehensive conclusions will be made.

AMR 15-3052

K-39. Kurabayasi, T.

3901. Kurabayasi, T., On the thicknesses of smooth jets discharged from a fixed and a rotating nozzle, *Bull. JSME* 3, 11, 358-363, Aug. 1960.

Droplet size produced from a continuous liquid jet depends mainly on its thickness. Author discusses the contraction of smooth liquid jets, issuing from a fixed and from a rotating nozzle, due to acceleration and surface tension, and presents formulas for it. The physical factors influencing the liquid jet are expressed by the Weber number; when this exceeds the value 4, the physical properties have no further influence on the thickness of the jet. For the length of the continuous portion of the jet paper presents the formula of Tanasawa and Toyoda. Relationship between the cases of a fixed nozzle and a rotating nozzle is discussed and good agreement is found between the values computed from the formulas and those obtained experimentally. Author suggests that the results are applicable to the filamentation of viscous liquids by means of a rotating nozzle. This paper, together with the preceding review, confirms some earlier research results, and contains some novel findings; they can be regarded as useful additions to previous spray literature.

AMR 14-3901

K-40. Kurabayasi, T.

3900. Kurabayasi, T., Atomization of liquid by means of a rotating nozzle (on the disintegration modes and droplet sizes), *Bull. JSME* 3, 11, 352-357, Aug. 1960.

Flow from rotating nozzles, and the behavior of the issuing jets, was studied by means of high-speed photography. A shallow cylindrical container, fed with liquid at its center, was rotated at high speed, producing thereby a strong centrifugal force on the liquid. The liquid issued through nozzles drilled into the cylindrical wall. Containers of 10 to 20-cm diam, nozzles of 0.4 to 1.2-mm diam, and flow rates of 0.1 to 6 cm^3/sec were employed. Five typical modes of disintegration could be distinguished: (1) dripping, (2) smooth jet, (3) wavy jet, (4) partially sprayed jet, and

(5) spray. Paper shows graphs of the Sauter mean diameter as a function of velocity, and presents mathematical expression for the region of wavy jet, and for the spray. The maximum diameter is found to be approximately twice the mean diameter.

AMR 14-3900

K-41. Kutateladze, S. S., and M. A. Strikovich

Kutateladze, Samson Semenovich and Styrikovich, Mikhayl Adol'fovich.
HYDRAULICS OF GAS-LIQUID SYSTEMS, ed. by L. A. Vitman. Sep 60 [321]p. 81 refs. F-TS-9814/V. Order from LC or SLA mi$11.10, ph$50.10 61-19366

Trans. of mono. Gidravlika Gaso-Zhidkostiykh Sistem, Moscow, 1958, 232p.

A systematic description is given of the most essential laws governing the combined motion of a gas and a liquid. The problems considered are: the motion of a gas-liquid mixture in pipes, bubbling, atomization of a liquid by mechanical and pneumatic spray nozzles, critical regimes of boiling, and several other problems. The book is designed for scientific workers, engineers, and students specializing in the fields of physical-heat engineering, power engineering, hydromechanics, chemical processes, and equipment. (Extracted from announcement by Soviet publisher)

T5-573

K-42. Kuznetsov, P. I., and L. Ia. Tslaf

6377. Kuznetsov, P. I., and Tslaf, L. Ia., On the breaking up of a fluid jet into drops, *Soviet Phys.-Tech. Phys.* 3, 6, 1135-1138, Feb. 1959. (Translation of *Zh. Tekh. Fiz., Akad. Nauk SSSR* 28, 6, 1220-1223, June 1958 by Amer. Inst. Phys., Inc., New York, N. Y.)

After discussion of previous researches the breaking up process is described as a succession of phenomena: attachment to the nozzle, clear glassy tubular shape, drops existing but not separated, separate drops. Present work deals with factors entering into dispersion of the jet; nozzle diameter, drop diameter (mean value), density of liquid, density of fluid into which the flow takes place, nozzle pressure at orifice, kinematic viscosity of liquid, kinematic viscosity of surrounding medium, surface tension of liquid sprayed, velocity of liquid upon leaving the nozzle, and the gravitational acceleration. The function connecting these ten quantities has to be determined experimentally. Authors apply to these quantities the Pi-theorem, and form seven dimensionless groups, but finally use only four of them, one of which is the Reynolds number. For cases of air at atmospheric pressure as the surrounding medium the function is dependent only on two dimensionless groups. Applying this function to a number of experiments the interrelations are represented graphically in logarithmic charts. Authors claim for their two-parameter function a better fit of experimental data than was given by functions developed by previous workers.

The paper is too condensed, the experimental values are not given, the data seem to be taken from one single nozzle of the impinging type, and the method of derivation is hazy. The method of determining the mean drop diameter is not given.

AMR 12-6377

L-1. Lacey, R. E., et al.

Factors Determining the Particle Size of Aerosols Generated by Hot-Gas Atomization. Robert E. Lacey, Edward W. Lang, Everett Huffman, and W. L. Mayfield (Southern Res. Inst., Birmingham, Ala.). Final Rep. to U.S. Army Chem. Center on Contr. No. DA-18-108-CML-6423; Sep. 30, 1959, 60 p., 26 fig., 2 tabl.

Procedures for sampling and counting of aerosols were developed, using a technique in which microscope slides were waved through the stream of aerosol; found that 1500 to 3000 particles should be counted for each aerosol sample for a reliable determination of mean particle diameter. The tip of the liquid injection tube in the gas stream was as close as possible to the furnace nozzle. Experimental program was divided into two phases: (1) Conditions necessary to produce particles smaller than 10 microns in diameter were studied; a set of equations were developed and experimentally validated. (2) Conditions were studied that result in bimodal distribution of aerosol particles; the mode of particles larger than 10 microns in diameter was characterized by the average surface-volume diameter. Three gas temperatures (1600°F., 1900°F., and 2200°F.), and three liquids were used, at several rates of liquid injection. Relation of surface-volume diameter of particles larger than 10 micron, the liquid flow rate per unit weight of gas, and gas temperature are shown for several liquid chemicals. Found no correlation between mean particle size and liquid properties: surface tension, viscosity, density, and energy of vaporization. Appendix treats calculation of design data of an atomizer to produce aerosols with particle size less than 10 microns, and aerosols with bimodal distributions.

deJ II-263

L-2. Laguilharpe, P. R.

"An Atomizer-Drier." P. R. Laguilharpe. Fr. 938,920, Oct. 28, 1948.

L-3. Lambrecht, J. and W. Alvermann

901. Lambrecht, J., and Alvermann, W., Atomization of fuel in jet engines (in German), ***Motortech. Z.*** **18,** 10, 318-321, Oct. 1957.

The requirements and characteristics of fuel injection in jet engines differ significantly from those in diesel engines, inasmuch as the injection is continuous and not intermittent, the fuel quantities are much larger, and space and time for combustion are small; furthermore, the energy of injection also should be kept small. The design of nozzles for turbojet engines (not for ramjet engines) is discussed; these are of the centrifugal type, producing a spray of 80 to 100 deg cone angle. The main dimensions of the nozzle which influence the Reynolds number, and hence the turbulence and spray characteristics, are: the length and diameter of the nozzle orifice, and the diameter, number and eccentricity of the tangential orifices serving the swirl chamber. The concepts of "efflux rate" and "flow number" are explained. The atomization is influenced also by the fuel properties, in particular by the viscosity and, to a lesser extent, by the surface tension, and by the density (temperature and pressure) of the combustion air. The concepts of "specific surface" of the spray, and the "mean Sauter diameter" of the droplets forming the spray are explained. The main types of nozzles: (a) "simplex" nozzles having constant exit orifice, (b) nozzles with variable orifice, depending on the fuel pressure, (c) "duplex" nozzles having two coaxial atomizing systems, (d) "return-flow"-type nozzles in which part of the supply fuel is returned to the tank, and (e) rotating-disk atomizers are discussed and illustrated.

AMR 11-901

L-4. Lane, W. R.

8556. Shatter of drops in streams of air. W. R. Lane. ***Industr. Engng Chem.,*** **43,** 1312-17 (*June,* 1951).

Using electronic flash and spark photography, stages of the shatter of individual drops exposed to steady and transient air streams were identified and interpreted in terms of fluid mechanics. The secondary droplets into which a drop was shattered were found to be progressively smaller as the velocity of the air stream was increased, but at the highest (supersonic) velocities used, they were not so small as would be predicted by extrapolating the relationship established for breakup in a steady air flow.

PA 54-8556

L-5. Lane, W. R. and H. L. Green

"The Mechanics of Drops and Bubbles," pp. 162-215 in "Surveys in Mechanics, G. I. Taylor 70th Anniversary Volume." Cambridge University Press, New York, 1956.

The mechanics of drops and bubbles are discussed, considering not only their dynamics but also the motion of fluid within and around them. The behavior of these systems presents problems not encountered in other branches of mechanics. By contrast to rigid spheres they may experience deformation, and then the two physical properties, surface tension and viscosity, exert a dominant influence. Internal circulation within the fluid of a drop or bubble may alter appreciably its dynamics and reaction with the surrounding medium.

The mechanics of drop formation is discussed first, and this is followed by an account of the motion of falling drops, their deformation and disruption. An important aspect is the deposition on obstacles of drops from a moving stream and the related problem of the collection of droplets in a cloud by a falling drop. The treatment is largely restricted to drops of macroscopic size formed in gas, leaving out of consideration such systems as mists, fogs and liquid aerosols in general, and fine liquid-liquid dispersions, commonly called emulsions.

Some chapter headings are: Shape of a pendant drop; Detachment of drops from tips; Production of drops: from tips, from spinning disk, and from swirl chamber; Behavior of falling drops: terminal velocity of spherical drop, swerving of drops, terminal velocity of large drops, empirical equations for terminal velocities, shape of falling drops, circulation in drops; Break-up of drops; Deposition of drops on obstacles from a moving stream; Collection efficiency of drops.

The section on bubbles deals with their formation, the dynamics of rising bubbles, and, finally, with the bursting of bubbles. With the exception of the last topic, the behavior of bubbles bounded by a liquid film (soap bubbles, foam, etc.) is not discussed. Bubbles can remain stable in sizes which are many orders of magnitude greater than the limiting size of drops. Chapter headings are: Production of bubbles: from orifices, from capillaries, "bubble rafts"; Behavior of rising bubbles: terminal velocity, vertical motion of large bubbles, large bubbles rising in tube.

AMR 11-30

L-6. Lang, R. J.

ULTRASONIC ATOMIZATION OF LIQUIDS.
2095 R.J.Lang.
J. Acoust. Soc. Amer., Vol. 34, No. 1, 6-8 (Jan., 1962).

An experimental study was made of the mechanism by which the ultrasonic vibration of liquid surfaces causes atomization. At exciting frequencies in the range of 10 to 800 kc/s, uniform patterns of crossed capillary waves were found on the liquid surface when atomization occurred. The number-median diameter of the particles produced was found to be a constant fraction, 0.34, of the capillary wavelength; the capillary wavelength is calculable by Kelvin's equation using the exciting frequency and properties of the fluid being atomized. The evidence is strong that the mechanism of ultrasonic atomization involves the rupture of capillary surface waves and the subsequent ejection of the wave peaks from the surface as particles.

PA 65-2695

L-7. Lang, R. J., J. C. O'C. Young, and J. A. Wilson

"An Ultrasonic Oil Burner." Proceedings of the API Research Conference on Distillate Fuel Combustion. Paper No. CP 62-7. June 1962.

L-8. Langa, J. M. and J. R. Davis

"Spray Characteristics of Converging Sprinkler Nozzles" Agricul. Engr. 40, 447-9 (Aug. 1959).

L-9. Langer, G. and A. Lieberman

"Anomalous Behavior of Aerosols Produced by Atomization of Monodisperse Polystyrene Latex"
J. Colloid Sci 15, 357-60 (1960)

A study was made of the uniformity of aerosol particles generated by the atomization of monodispersed polystyrene latices. It was found that the stabilizer associated with the latices formed extraneous particles as well as increased the size of the polystyrene particles. This was due to the fact that the stabilizer binds water strongly even in the presence of dry air. Heat drove the bound water off but adversely affected the polystyrene particles.

Author

L-10. Langlais, L.

"A Dynamic Supersonic Generator of Aerosols."
L. Langlais. Rev. path. comparée et hyg. gén. 50, 466-72 (1950).

CA 44-8172a

L-11. Larcombe, H. L. M.

"Principles of Pressure Spray Nozzles." Chem. Age (London) 57, part I, 563-6; part II, 597-8; part III, 621-3 (1947).

L-12. Larsen, R. G. and J. R. Joyce
"Atomization." pp. 155-208 in "Advances in Petroleum Chemistry and Refining. Vol. V." J. J. McKetta, Ed. Interscience, New York, 1962.

L-13. Laster, R. and M. Doumas

"Review of Theoretical and Mathematical Analyses of the Performance of Atomizing Nozzles."
Chem. Eng. Prog. 49, 518-26 (1953).

L-14. Lastovtsev, A. M.

5810. Lastovtsev, A. M., The hydrodynamic analysis of rotating atomizers (in Russian), *Trudi Mosk. In-ta Khim. Mashinostr.* 11, 41-70, 1957; *Ref. Zh. Mekh.* no. 2, 1958, Rev. 1841.

The motion of a fluid in rotating atomizers with variously directed orifices, cross sections and profiles is examined. The following assumptions are made: (a) Friction between the free surface of the liquid in the atomizer channel and the air is negligible; (b) the transverse components of the flow velocity are negligible; (c) the liquid moves without hydraulic pressure, merely by the action of centrifugal inertia forces. A differential equation is derived for the turbulent flow of a liquid in an atomizer. Analytical expressions are set up for determining the relative velocity of the liquid at the edge of the atomizer. It is found experimentally that the expressions obtained are applicable in a wide range of variation of the angular velocities and dimensions in the atomizers, as well as the loads in the channels.

AMR 12-5810

L-15. Lastovtsev, A. M.

5809. Lastovtsev, A. M., The throughput capacity of rotary atomizers (in Russian), *Trudi Mosk. In-ta Khim. Mashinostr.* 11, 71-82, 1957; *Ref. Zh. Mekh.* no. 2, 1958, Rev. 1842.

An experimental determination of the relationship between the limiting volumetric throughput of an atomizer Q_n and its angular velocity, cross-sectional area of the orifice, number of orifices, radius of the intake orifices of the receiving chamber, and the radius of the receiving chamber in the plane of the orifices through which the liquid issues. Also verified is the influence on Q_n of the length of the atomizer channels, the construction of the receiving or intake chamber, and the physical properties of the working fluid. Atomizers of 19 different sizes were tested. A formula has been obtained for calculating the limiting throughput capacity of rotary atomizers.

AMR 12-5809

L-16. Lastovtsev, A. M.

"Estimation of Dispersion of Atomized Liquids."
A. M. Lastovtsev. Trudy Moskov. Inst. Khim. Mashinostroeniya 1950, No. 2 (Whole No. 10), 3-18.

CA 48-4931f

L-17. Latham, J.

9779 THE MASS LOSS OF WATER DROPS FALLING IN ELECTRIC FIELDS. J. Latham.
Quart. J. Roy. Meteorol. Soc. (GB), Vol. 91, 87-90 (Jan. 1965).

Experiments showed that water drops of radius 0.191 cm falling for 0.2 seconds through a horizontal electric field were disrupted and lost mass if the field strength exceeded 8500 V cm^{-1}. As the field strength was increased above this critical value the mass loss increased rapidly and in a field of 11 500 V cm^{-1} the drop lost about 35 per cent of its mass; for higher values of field strength the mass loss increased more slowly. Experiments also showed that the magnitude of the mass loss was dependent upon the time of exposure of the drop to the field. For exposure times less than about 2×10^{-2} sec drops falling in a field of 11 250 V cm^{-1} lost no mass but as the exposure time was increased above this value the mass loss increased rapidly and for an exposure time of about 0.1 sec the mass loss was 25 per cent; for longer exposure times the mass loss increased more slowly. An assessment is made of the importance of this disruption process in modifying the concentration and size distribution of raindrops and cloud droplets inside a thundercloud.

PA 68-9079

L-18. Lauterbach, K. E., A. D. Hayes, and M. A. Coelho

14874 An Improved Aerosol Generator. K. E. Lauterbach, A. D. Hayes, and M. A. Coelho. *University of Rochester (U.S. Atomic Energy Commission)*, UR-377, July 1955, 15 p. (UF767 Un3.1ru)

Produces heterogeneous aerosols from either suspensions of ground insoluble materials or solutions of soluble compounds, with only minor fluctuations in mass concentration. Particle size and concentration of the aerosol have been related to the concentration of soluble material. Tables, diagrams.

BMI 4-14874

178

L-19. Lawrence, O. N.

Gas Turbine Accessory Systems. O. N. Lawrence. Jl. Roy, Aero. Soc. (Engl.) Vol. 1948, pp. 151–185, 15 fig., 2 ref.

Chapter on atomization (pp. 153–156) discusses the limitations of the "Simplex" (Monarch) nozzle as well as those of "duplex" and "spill" nozzles. Difficulty arises from wide flow range of 30 : 1 between maximum rate (sea level full power) and minimum rate (high altitude, idling). Possibility of air injection is briefly mentioned. Discussions by numerous research workers contain references to nozzle problems.

deJ I-200

L-20. Lebedev, L. V.

"A Sprayer for Fine Spraying of Liquids at Low Pressure and Low Output" Fiziol. Rastenii 7, No. 1, 127-8 (1960).

L-21. Lee, D. W.

A Comparison of Fuel Sprays from Several Types of Injection Nozzles. D. W. Lee. NACA Rept. No. 520 (Dec. 1935), 38 p., 28 fig., 35 ref. with abstracts.

Motion pictures were used to measure penetration; these and impressions on Plasticine targets were used to draw qualitative pictures of spray structure. 14 fuel injection nozzles of 9 different types were used (plain orifice, multiple orifice, lip nozzle, impinging jets, annular orifice, slit nozzle, centrifugal, pintle-type, and helical groove in orifice walls). Air chamber density was 1, 6, and 14 atm. Photographs taken at the rate of 2000 per sec. Spray characteristics are evaluated with respect to their application to various types of engines.

deJ I-202

L-22. Lee, D. W.

Experiments on the Distribution of Fuel in Fuel Sprays. D. W. Lee. NACA TR 438 (1932).

Distribution of fuel in sprays was investigated by photographing them under various conditions, and also by injecting them against Plasticine targets. Photographs of sprays from plain nozzles injected into an evacuated chamber, into the atmosphere, into compressed air, and into transparent liquids. Pairs of identical sprays injected against each other under various conditions. Small, high-velocity air jets were directed normally to the axis of sprays; photographs show the spray envelope being blown aside, exposing the spray core. Photographs are discussed.

deJ I-201

L-23. Lee, D. W.

Fuel Spray Formation. D. W. Lee (NACA). Penn. State Coll. Techn. Bull. No. 16 (1933), pp. 53–72, 14 fig. Trans. ASME Vol. 54 (1932), OGP Soc. pp. 63–73, 14 fig., 12 ref.

Summary of work on this subject by NACA up to 1932. Diameters of fuel drops in sprays from different types of nozzles were measured and the effects of fuel-injection pressure, nozzle dimensions, and the density of the chamber air on the atomization of sprays were determined. Photomicrographs of droplets caught on a smoked plate; high-speed spark photographs of fuel sprays. Photographs show transformation of solid jet into atomized spray, and effect of several factors on spray dispersion. Comparison with the results of other workers.

deJ I-201

L-24. Lee, D. W.

The Effect of Nozzle Design and Operating Conditions on the Atomization and Distribution of Fuel Sprays. D. W. Lee. NACA Tech. Rept. 425 (Febr. 1932), 19 p., 25 fig., 20 ref.

Measurement of droplet size and distribution by the smoked plate method. Spray direction horizontal, smoked plate placed horizontally under spray, the drops falling on it by gravity. Chamber pressure and injection pressure varied over wide range. Several nozzles used (0.008, 0.020, 0.028, and 0.030 in. dia. orifice) varied as regards internal design, orifice diameter, and length-diameter ratio. Results expressed in "atomization curves" with "group mean diameter" as abscissas, and "percentage by number" or "percentage by volume" as ordinates. Finds that fineness and uniformity of atomization improve with higher injection pressure (efflux velocity) and with smaller orifice size. Air density effect is negligible. Drop size range was from 0.00025 to 0.005 in., occasionally 0.010 in.

deJ I-201

L-25. Lee, D. W. and R. C. Spencer

Photomicrographic Studies of Fuel Sprays. D. W. Lee and R. C. Spencer. NACA TR 454 (1933). 27 p., 25 fig., 12 ref.

Basic experimental study of spray formation. A large number of photomicrographs of fuel sprays are shown, taken at magnifications of 2.5, 3.25, and 10. Several types and sizes of nozzles were used with different fuels, and wide range of injection pressures; density of the air into which the sprays were injected ranged from 0.0013 to 14 atmospheres. The photomicrographs are explained, and atomization data from some of them are compared with data from other sources. Electric circuit used for spark illumination; types of jet disintegration; ligament formation; effect of turbulent flow, of air density, of dimensions and condition of orifices, of injection velocity, of different liquids. Comparison of drop-size distribution curves as obtained by several investigators.

deJ I-202

L-26. Lee, D. W. and R. C. Spencer

Preliminary Photomicrographic Studies of Fuel Sprays. D. W. Lee and R. C. Spencer. NACA Tech. Note 424 (June 1932).

Photographs show ligament formation on jet surface prior to detachment of small drops.

deJ I-202

L-27. Leighton, W. B.

"Instrumentation for Aerosols." W. B. Leighton (Union Carbide Chem. Co., New York, N. Y.). Soap Chem. Specialties 34, No. 8, 79-81, 83, 89, 91 (1958).

CA 52-178221

L-28. Lewis, D. J.

6291. The instability of liquid surfaces when accelerated in a direction perpendicular to their planes. II. D. J. Lewis. *Proc. Roy. Soc. A*, 202, 81-95 (*June* 22, 1950).

An apparatus for accelerating small quantities of various liquids vertically downwards at accelerations of the order of 50 g (g being 32·2 ft./sec.²) is described, and the behaviour of small wave-like corrugations initially imposed on the upper liquid surface has been observed by means of high-speed shadow photography. The instability observed under a wide variety of experimental conditions has been analysed, and the initial phases have been found to agree well with the first-order theory given in Part I [see Abstr. 3808 (1950)]. When the disturbance has attained a considerable amplitude the first-order equations cease to apply and it changes from a wave into a form which has the appearance of large round-ended columns of air extending into the liquid and separated by narrow sheets of liquid. The air columns attain a steady velocity relative to the accelerating liquid and continue to penetrate into the liquid until the lower surface of the liquid is reached. In spite of these very large surface disturbances, the main body of liquid below them is accelerated as though they did not exist.

PA 53-6291

L-29. Lewis, H. C. et al.

Atomization of Liquids in High Velocity Gas Streams. H. C. Lewis, D. G. Edwards, M. J. Goglia, R. I. Rice, and L. W. Smith (Univ. of Illinois). Ind. Eng. Chem., Vol. 40 (Jan. 1948), pp. 67–74, 7 fig., 20 ref.

Empirical equations by Nukiyama and Tanasawa for air-atomizing nozzles are discussed; it is shown that drop size distribution can be expressed by a straight-line relation. Data in the literature are analyzed and good agreement with these equations is found for gas atomizing nozzles, fair agreement for liquid spray nozzles. Experiments on gas-atomizing nozzles are described (Venturi atomizers having 0.107 in. 0.500 in., and 3.34 in. throat diameters were used), corroborating and extending the work by Nukiyama and Tanasawa (NUKIYAMA and TANASAWA 1940) and illustrating the effects of gas density, gas viscosity, heat transfer from gas to liquid, and the scale of the apparatus, on the performance of gas-atomizing nozzles.

deJ I-204

L-30. Lewis, J. D.

"Studies of Atomization and Injection Processes in the Liquid Propellant Rocket Engine" Fifth AGARD Comb. and Prop. Coll., Pergamon Press, 1963.

L-31. Limper, A. F.

Atomization of Liquids by Injection into High Velocity Gas Streams. A. F. Limper. M. S. Thesis, Univ. Illinois (1947), 51 p., 19 fig., 18 ref.

Injection of water and light lubricating oil into throat of 1 in. and 4 in. venturis, axially and radially. Venturis of 1 inch and 0.5 inch diameter, having diffusor angles of 7 to 15 degs. were used. Measures pressure loss, per cent atomized, drop size distribution. Below an exit velocity of 400 ft./sec. some liquid remains unatomized. Axial injection into the center of venturi throat is most efficient. Liquid velocity should be low in comparison with gas velocity. Divergent venturi section should be short. Used a spray sampler described in PIERCE 1947. Finds that atomization can be predicted from the equations of Nukiyama and Tanasawa, if gas velocity is above 300 ft./sec.

deJ I-206

L-32. Littaye, G.

Influence de la Vitesse de l'Air sur le Diamètre des Petites Gouttes Obtenues par Atomization Pneumatique (Influence of Air Velocity on the Diameter of Very Small Drops Obtained by Pneumatic Atomization). Guy Littaye. Compt. Rend. (France) Vol. 218 (1944), pp. 440–441, 1 fig., 4 ref.

Disagrees with the finding in CASTLEMAN 1931 that a limiting value of the order of several microns exists below which the diameter of the drops cannot decrease no matter how great the relative velocity is. Experiments on a liquid jet exposed to an air jet show that the drop size decreases steadily as the velocity is increased in the investigated range, down to one micron diameter. Drops of less than one micron dia should be obtained if the air velocity exceeds 300 ft./sec. Alcohol at 50° and water were used in the experiments. Concludes that in solid injection the action of air on the jet is not the only cause of the production of fine drops.

deJ I-208

L-33. Littaye, G.

Sur une Théorie de la Pulverisation des Jets Liquides (Theory of the pulverization of liquid jets). Guy Littaye. Compt. Rend. (France), Vol. 217 (July 1943), pp. 99–100, 1 fig.

Considers low velocity liquid jet directed perpendicularly to a current of gas. Three modes of break-up obtained, depending on the gas velocity: (1) drop formation; (2) pulverization; (3) pneumatic atomization. Extends the work SIESTRUNCK 1942 to the region of pneumatic atomization. Gives logarithmic graph showing the 3 modes, verifying the theory that in the third mode the gas velocity is independent of the jet diameter.

deJ I-207

L-34. Littaye, G.

Sur l'Atomization d'un Jet Liquide (Atomization of a liquid jet). Guy Littaye. Compt. Rend. (France), Vol. 217 (Oct. 1943), pp. 340–342.

Uses the analysis of SIESTRUNCK 1942 to develop an equation relating drop size to relative velocity, surface tension, and gas density:

$$\frac{\rho (V-v)^2 D}{\tau} = \text{const.}$$

Where ρ = the density of the gas, V = velocity of gas, v = velocity of drop, D = diameter of drop, τ = surface tension of the liquid. In air, for a drop of water having negligible velocity the relation $V^2 D = 1.12 \times 10^6$ has been found by experiment.

deJ I-207

L-35. Littaye, G.

Contribution a l'Etude des Jets Liquides (Study of liquid jets). Guy Littaye (Faculté des Sciences, Laboratoire de Mécanique des Fluides, Paris, France; M. Foch, Directeur). Publications Scientifiques et Techniques du Secretariat d'Etat a l'Aviation (1942). 103 p., 62 fig., 22 ref.

Contraction of liquid stream; jet issuing from a thin-plate orifice, and froma capillary tube; influence of surface tension; experiments for determining the jet diameter and amount of discharge. Capillary phenomena in a liquid jet; spark photography, projecting the shadow of the jet onto two planes perpendicular to ane another; vibration of jet issuing from a thin-plate orifice and from a capillary tube; coagulation of drops. Study of jets of moderate velocity; transverse oscillation; variation of cross-section; experiments on jets issuing from a capillary nozzle; various kinds of transverse oscillations. Concludes that capillarity and turbulence do not explain fully the atomization; an important part is played by the turbulence of the surrounding air, and the centrifugal force on the liquid produced thereby. Distinguishes three phases in the break up of the liquid: capillary oscillation, transversal oscillation, and atomization. Transversal oscillation shown by spark photography is of special interest.

deJ I-207

L-36. Loeb, L. B.

Book—3826. Loeb, L. B., Static electrification, Berlin, Springer-Verlag, 1958, 240 pp. + 63 figs.

Chapter III discusses the electrification by spraying and bubbling of liquids with the generation of potential across liquid-gas and liquid-liquid surfaces. Then follows discussion of cataphoresis of gas bubbles, with the formation of electrical double layer at liquid-gas interfaces. The recently discovered spray electrification phenomenon on the positive charge carried aloft on spray from sea water bubbles caused by breaking waves is discussed, with its meteorological implications involving coastal haze. The studies of DODD on symmetrical charging of sprayed liquid droplets is presented, and the importance on the falsification of data on spray charging mechanisms is discussed.

AMR 11-3826

L-37. Lohnstein, T.

"On the Theory of Drop Formation, with Special Reference to the Determination of Capillary Constants by Means of Droplet Experiments". Ann. der Physik, p. 20 , 1906

L-38. Longwell, J. P.

Fuel Oil Atomization. John P. Longwell. D. Sc. Thesis, M.I.T., (1943), 167 p., 38 fig., 6 ref.

Determination of drop size distribution by frozen drop method with sieving procedure, applied to swirl chamber nozzles for oil burners. Orifices from 0.315 to 0.111 in. diameter, pressures 30 to 300 lb./sq. in., viscosity from 0.082 to 0.88 poises. Empirical correlations of mean droplet size, cone angle, injection pressures, orifice diameter, viscosity, drop size distribution, discharge rates, limits of atomization, nozzle design. Comparison of experimental results with the Rosin-Rammler formula. Prediction of nozzle performance from physical dimensions of the types of nozzles investigated.

deJ I-209

L-39. Longwell, J. P. and M. A. Weiss

"Mixing and Distribution of Liquids in High-Velocity Air Streams." John P. Longwell and Malcolm A. Weiss (Standard Oil Development Co., Linden, N. J.). Ind. Eng. Chem. 45, 667-76 (1953).

CA 47-6193h

L-40. Lovikov, P. F.

174. Lovikov, P. F., Influence of the concentration of liquid products on the dimensions of the drops of a liquid and their range of flight (in Russian), *Trudi Leningr. tekhnol. in-ta kholodil'n. prom-sti* 7, 61–64, 1955; *Ref. Zh. Mekh.* 1956, Rev. 5170.

An experimental investigation was made of the influence of a concentration of solid substances in a solution which can be atomized with the aid of a rotating disk upon the average dimension of the drops.

An aqueous solution of gelatine with sugar was supplied to the rotating disk; the drops were caught on a glass plate covered by a layer of a mixture of machine oil and vaseline and then measured under a microscope. During the tests the concentration of dry substances in the liquid which can be atomized varied within the limits of 10 and 45%. The tests showed that with increase of the concentration of the dry substances the average dimension of the drop increases according to a linear law.

AMR 11-174

L-41. Lubbock, I. and I. G. Bowen

"The Effects of Cone Angle, Pressure, and Flow Number on the Particle Size of a Pressure Jet Atomizer" Shell Tech. Report No. ICT 17. 1948.

L-42. Luther, F. E.

"Electrostatic Atomization of No. 2 Fuel Oil," API Res. Conf. on Distill. Fuel Combust. Proc., (1962), API Pub. 1701. An electrostatic atomizer for No. 2 fuel oil developed. 40 micron MMD and up reported, where MMD is directly proportional to flow rate. A cone and ring electrode configuration used. Effect of using DC voltage, AC voltage and a combination of them examined.

Author

L-43. Lyshevskii, A. S.

Lyshevskii, A.S.
DETERMINATION DE LA PRESSION AXIALE DU JET D'UN FLUIDE (SORTANT DE LA BUSE D'UN TREPAN A JETS). Org.175-T.1909.
Order from CNRS G/R-4112

Trans. in French of Izvestiya Vysshikh Uchebnykh Zavedenii. Neft' i Gaz (USSR) 1963 [v.6] no.6, n.p.

T13-617

L-44. Lyshevskii, A. S.

"Design of Jets for Mechanical Sprayers." A. S. Lyshevskii (Polytech. Inst., Novocherkassk). Izv. Vysshikh Uchebn. Zavedenii, Khim. i Khim. Tekhnol. 6(5), 865-73 (1963).

CA 60-11628h

L-45. Lyshevskii, A. S.

Lyshevskii, A. S.
VARIATION IN THE VELOCITY DISTRIBUTION IN AN UNBROKEN CIRCULAR JET OF A FLUID.
9 Jan 64, 7p 6refs JPRS: 22668 (p. 106-112).
Order from OTS $3.00 in TT-64-21246 (p. 106-112)

Trans. of Izvestiya Vysshikh Uchebnykh Zavedenii. Aviatsionnaya Tekhnika (USSR) 1963 [v. 6] no. 2, p. 87-91.

T 11-594

L-46. Lyshevskii, A. S.

2459. Lyshevskii, A. S., Study of the motion of a stream of atomized liquid (in Russian), *Trudy Novocherk. Politekh. In-ta* 112, 39-53, 1961; *Ref. Zh. Mekh.* no. 6, 1962, Rev. 6 B 234.

The author, on the basis of his previously established principles on the motion of a stream of liquid atomized by a jet with cylindrical nipples [*Izv. Vyssh. Uchebn. Zavedenii: Energetika* no. 6, 136-144, 1960], compares the experimental data obtained by various investigators. The first stage was the analysis, made with the aid of nondimensional criteria, of the results of the examination of a stream of atomized liquid at constant pressures for spraying. The next was an analogous analysis concerning data obtained with various pressures for spraying and the data characterizing the boundary between the initial and the main portions of the stream. It was established that in all the cases the influence exerted by the basic criteria on the parameters of the motion of the stream remains unchanged. A small difference in the numerical values for the coefficients is explained by lack of precision in the evaluation of the maximum pressure for the spraying, the coefficients of discharge of the nipples and some of the physical constants of the liquid.

AMR 17-2459

L-47. Lyshevskii, A. S.

3986. Lyshevskii, A. S., The axisymmetrical break-down of a round jet of viscous liquid (in Russian), *Izv. Vyssh. Uchebn. Zavedenii: Energetika* no. 7, 97-107, 1960; *Ref. Zh. Mekh.* no. 9, 1961, Rev. 9B 427.

A brief review is furnished of works dealing with the theoretical analysis of the stability and breakdown of jets of liquid. A solution is given of the problem on the axisymmetrical oscillations and breakdown of a round jet of a viscous liquid moving with a certain velocity relative to the air. In the analysis the usual method of small perturbations is employed, which enables the conditions to be found for the axisymmetrical breakdown of the jet into drops as the result of the solution of the problem on the eigenvalues for the equation of the fourth order with corresponding boundary conditions. The complex transcendental equation obtained in this way for the frequency of the oscillations is successfully simplified for several particular cases which are of practical interest.

An investigation is carried out of a particular case of breakdown of a jet of liquid of low viscosity in a surrounding medium of low viscosity. In this case the motion should not differ greatly from the potential. Then the transcendental equation for the frequency of the oscillations mentioned above is merged with a quadratic equation. A formula is obtained for the oscillation's frequency which enables an analysis to be made of the influence exerted by the basic parameters on the breakdown of the jet. A formula is derived, by using the Rayleigh hypothesis, for the dimensions of the drops obtained when the jet breaks down. A comparison is carried out of the results of the calculation for the diameter of the drop with the experimental data of various investigators during their study of axisymmetrical breakdown of jets of liquid. Satisfactory agreement was obtained between the theory and the data of these experiments (for the diameter of the drop and for the length of the unbroken part of the jet).

AMR 16-3986

L-48. Lyshevskii, A. A.

Lyshevskii, A. A.
EXPERIMENTAL INVESTIGATION INTO THE DEVELOPMENT OF THE JET OF ATOMIZED LIQUID AND THE GENERALIZATION OF EXPERIMENTAL RESULTS ON THE ANGLE OF THE JET'S CONE (Eksperimental'noe Issledovanie Razvitiya Strui Raspylennoi Zhidkosti i Obobshchenie Opytnykh Dannykh po Uglu Konusa Strui). June 63 [27]p. 9 refs. RTS 2272.
Order from OTS or SLA $2.60 63-23237

Trans. of Politekhnicheskii Institut, Novocherkassk. Trudy (USSR) 1960, v. 107, p. 3-22.

DESCRIPTORS: *Jets, *Liquid jets, Liquids, *Atomization, Test equipment, Test methods, Experimental data, Equations, Nozzles, *Fluid flow, Fuel sprays, Fuel injection, *Fuel oil.

T 10-961

L-49. Lyshevskii, A. S.

Lyshevskii, A. S.
A STUDY OF THE LAWS OF MOTION OF AN ATOMIZED STREAM OF LIQUID. 1 Mar 62 [14]p. 7 refs. FTD-TT-61-414.
Order from OTS or SLA $1.60 62-23664

Unedited rough draft trans. of Izvestiya Vysshikh Uchebnykh Zavedenii. Energetika (USSR) 1960 [v. 3] no. 6, p. 136-144.

DESCRIPTORS: Liquids, *Fuel sprays, *Atomization, Hydrodynamics, Fuel injection, Pressure, Spray nozzles, High-speed photography.

The motion of an atomized stream of liquid was investigated on specially constructed apparatus. The apparatus consisted of a twelve-piston fuel pump run by a d.c. electric motor, a high-pressure fuel collector, a special chamber and a camera for taking high-speed pictures. Three series of experiments were made: the first series was at various air counter pressures in the chamber, the second at various injection pressures and the third at various nozzle aperture diameters. When measuring one of the characteristic parameters, all others remained strictly unchanged in the experiment. The results obtained from the investigation were used to establish the fundamental laws of motion of an atomized stream of liquid.

T 9-535

L-50. Lyshevskii, A. S.

1129. Lushevskii, A. S., The stability and the breakdown of a hollow jet of viscous liquid moving at small velocities (in Russian), *Izv. Vyssh. Uchebn. Zavedenii. Energetika* no. 3, 95-102, 1958; *Ref. Zh. Mekh.* no. 3, 1959, Rev. 2672.

The problem described in the title is investigated theoretically; the jet is issuing from a sprayer. It is considered that capillary waves spread from both sides of the cylindrical film; the waves with increasing amplitudes reach the point leading to the breakdown of the film into separate annular segments which ultimately are reduced to drops. The author obtained an equation for the function of the current of the disturbed motion by starting from the Navier-Stokes equations and utilizing the method of small excitations. The particular solution of the author's equation can be presented as consisting of vortexless and vortex-containing portions. Continuing, the author obtained a transcendental equation linking the increment imposed on the jet of small excitations with all the parameters determining the breakdown of the jet; this was made possible by the author's use of the boundary conditions on the outer and inner free surfaces of the hollow jet. Because of the complexity of the transcendental equation obtained, the analysis was restricted to a single case of breakdown of the film. It was assumed that the forces of inertia of the liquid are small by comparison with the forces of viscosity and can therefore be disregarded. Only the long-wave vibrations are investigated. As the result of adopting these simplifications a quadratic equation is obtained for the vibrations increment and a formula is derived for the optimum length of the vibration wave, corresponding to the maximum increment. It is established theoretically that as the film gets thinner and as the viscosity of the jet diminishes the length of the vibration wave becomes smaller, corresponding with the maximum degree of instability. It is shown that, in consequence of the above, a hollow jet of liquid breaks down into smaller parts than a round jet. A formula is also obtained for the calculations of the portion of the jet which does not disintegrate.

AMR 14-1129

L-51. Lyshevskii, A. S.

295. Lyshevskii, A. S., The influence of the surrounding medium on the disruption of a hollow jet of liquid (in Russian), *Izv. Vyssh. Uchebn. Zavedenii. Energetika* no. 6, 108-112, 1958; *Ref. Zh. Mekh.* no. 5, 1959, Rev. 5027.

An investigation is carried out of the stability and the conditions governing the breaking up of a jet of liquid issuing from a round orifice, the basis of the investigation being the application of the method of small disturbances. The liquids (the jet and the surrounding medium) are taken to be ideal, incompressible and imponderable with their motion-potential and symmetrical. When analyzing the stability of the ring jet it is assumed that the conditions of development of the disturbances from the inner and outer sides are wholly identical. When this is the case the solution of the problem is simplified to a considerable extent. The author, after bringing into operation the usual boundary conditions for the surfaces of the hollow jet, arrives at a quadratic equation for the vibrations' increment, the solution of which opens up the possibility of determining the influence of a number of parameters on the characteristics of the jet's stability. It is shown that with a decrease in the film thickness the magnitudes of the maximum values of the vibrations' increment become larger, which means that the time of the break-up or the length of the unbroken part of the jet shorten as the attenuation of the cylindrical film becomes more marked. It was also established that with an increase of Weber's criterion $W = u^2 q_1 r_2/\sigma$ (where u is the velocity of the jet, q_1 the density of the medium surrounding the jet, r_2 the external radius of the cylindrical film, σ the coefficient of surface tension) and an increase in the relation $q = q_2/q_1$, where q_2 is the density of the jet's liquid, the maximum value of the vibrations' increment increases and moves toward the region of large wave numbers; that is, here again the length of the unbroken portion of the jet shortens and the film breaks up into smaller fragments.

AMR 14-295

L-52. Lyshevskii, A. S.

349. Lyshevskii, A. S., Application of the turbulent diffusion laws for investigation of scattering of liquid streams out-flowing from small apertures (in Russian), *Naucbn. Trudi Novocherkasskii Politekhn. In-ta* no. 39 (53), 49–66, 1957; *Ref. Zb. Mekh.* no. 1, 1958, Rev. 830.

Equations of the turbulent diffusion of the liquid compound in the axisymmetrical air stream can be linearized by the partial exchange in the equations of mean-point-values of velocity, by the mean value throughout the cross section of the stream. The equations so obtained are analogous to the heat-convection equations and can be integrated by the conventional means. Theoretical results are compared with experimental data concerning the atomization of fuels. The theory agrees well with experiment in cross sections remote from the pipe outlet where the concentration of the liquid mixture is sufficiently small.

AMR 13-349

L-53. Lyshevskii, A. S.

2071. Lyshevskii, A. S., Some characteristics of the widening of the jet of sprayed liquid in a medium offering counterpressure (in Russian), *Naucbn. Trudi Novocherkasskii Politekhn. In-ta* **39**, 53, 71–79, 1957; *Ref. Zb. Mekh.* no. 11, 1958, Rev. 12577.

The semi-empirical relation is given of the angle of conicity of the jet of sprayed liquid, ejected from the sprayer, to the geometrical form of the outlet orifice (a cylindrical orifice, a conically tapering orifice, a conically expanding orifice and others) and to the Reynolds number. This relation is based on one side on the theory of the free jet; on the other, on Gol'fel'der's experiments [DVS. Sb. Monogr. po in. Lit., ONTI NKTP SSSR, 1936].

AMR 13-2071

L-54. Lyshevskii, A. S.

5304. Lyshevskii, A. S., Determination of boundary velocities when liquid streams disintegrate (in Russian), *Naucb. Trudi Novocherkasskii Politekhn. In-ta* **39**, 53, 67–70, 1957; *Ref. Zb. Mekh.* no. 4, 1958, Rev. 4075.

An empirical formula is given for the determination of the limits of different forms of the breaking-up of streams of water: (1) disintegration of the stream without reaction by atmospheric forces, (2) disintegration with such forces, (3) disintegration, with the formation of a wave outline. The boundaries between the forms of stream disintegration are determined by analysis of the results of experiments by O. Gol'fel'der [Process of disintegration of a stream in relation to the form of the jet and the counter pressure, Vol. 1. S. N. Vasil'ev, Editor, ONTI, NKTP, SSSR, 1936], with the application of the theory of dimensions; the equations of these boundaries have the form of

$$W = A\pi^m \qquad 5(a)$$

where π is the relation of the density of liquid ρ_l to the density of the air ρ_a

$$W = U_n^2 \rho_l d_c \alpha^{-1},$$

U_n being the velocity of the stream, d_c the diameter of the jets' outlet, α the surface tension of the liquid. For every boundary the numerical values of A and m were found. There are inaccuracies in the author's reasoning. He disregards the influence of [illegible] viscosity on the grounds that in the experiments the coefficient of viscosity remained a constant, but the same thing could be said in regard to the surface tension. Author holds the view that equation 5(a) is derived on the basis of the theory of similarity, whereas the theory of similarity only indicates that W appears to be a function of π and that the presentation of the relation of W to π in the form of a stepped function is only a permissible hypothesis.

AMR 12-5304

L-55. Lyshevsky, A. S.

5676. Lyshevsky, A. S., The influence of turbulence on the disintegration of a fluid jet (in Russian), *Naucbn. Tr. Novocherkassky Politekhn. In-ta* **39**, 53, 81–86, 1957; *Ref. Zb. Mekh.* no. 2, 1958, Rev. 1840.

Paper analyzes the findings of various authors who have investigated the characteristics of fluid flow in the jet nozzles of burners for atomized fuels. By suitable treatment of the nondimensional parameters of experimental data on the length of the undisturbed jet, obtained by a number of research workers, the following formulas have been derived:

$$\frac{l}{d_c} = cW^{-m}R^{-n}, \qquad W = \frac{u_c^2 \rho_m d_c}{\alpha}, \qquad R = \frac{u_c d_c}{\nu_m}$$

where l is length of undisturbed length of jet; d_c diameter of nozzle aperature, u_c velocity of issuing fuel jet; ρ_m, ν_m density and coefficient of kinematic viscosity of the fuel, α coefficient of surface tension of the fuel. Values are cited for the coefficient c and the exponents m and n for three sections, according to the R number, corresponding to three states of outflow of the fuel from the nozzle aperture: laminar ($c = 8.22 \times 10^4$, $m = 0.4$, $n = 0.268$); tranational ($c = 6.91 \times 10^{9}$, $m = 0.4$, $n = 0.546$), and turbulent ($c = 1.4 \times 10^{7}$, $m = 0.4$, $n = 0.933$). It is concluded that turbulence is one of the causes of the disintegration of fluid jets.

AMR 12-5676

L-56. Lyshevsky, A. S.

5677. Lyshevsky, A. S., The problem of the coefficient of free turbulence in a jet of atomized liquid fuel (in Russian), *Trudi Novocherkas. Politekhn. In-ta* no. 33/47, 239–248, 1956; *Ref. Zh. Mekh.* no. 2, 1958, Rev. 1992.

An approximate method is proposed for determining the coefficient of free turbulence of a jet of atomized fuel required for constructing the concentration fields of the liquid. The analysis is founded on the theory of the turbulent gas jet developed by G. N. Abramovich ["The turbulent free jets of liquids and gases," Energoizdat, 1948], with allowance for the phenomenon of dissipation of the jet. Using the method of dimensional analysis the experimental data of Miller and Birdsley are analyzed in nondimensional parameters, and a relationship is obtained between the coefficient of free turbulence of the jet and the air density and outflow characteristics of the fuel.

AMR 12-5677

L-57. Lyshevskii, A. S.

936. Lyshevskii, A. S., A method for numerical determination of the fuel jet length in dense air (in Russian), Construction, research, trial of automobiles, no. 2, Moscow, Mashgiz, 1956, 44–53; *Ref. Zh. Mekh.* no. 1, 1958, Rev. 399.

A formula for determination of the length of flare is produced, based on the assumption that the fuel jet injected by a cylindrical nozzle into highly compressed air forms the free turbulent stream. The value of the nondimensional coefficient in the formula is determined on the basis of experimental results. A sample calculation is given. The calculations are compared with experimental results of several authors.

AMR 13-936

L-58. Lyshevskii, A. S.

504. Lyshevskii, A. S., Determination of jet length of atomized fuel (in Russian), *Nauch. Trudi Novocherkas. Politekhn. In-ta* 26, 391–401, 1955; *Ref. Zh. Mekh.* no. 1, 1958, Rev. 398.

The general equation is given for the length of jet (the depth to which the atomized fuel penetrates into a compressed air medium). The equation is checked by several experimental results published in the appropriate literature. Graphs are produced confirming the exactness of the relationship formula, which in general is based on theoretical considerations.

AMR 13-504

M-1. Macky, W. A.

1318. Deformation and Breaking of Water Drops in Strong Electric Fields. W. A. Macky. *Roy. Soc., Proc.* 133. *pp.* 565-587, *Oct.* 1, 1931.—Drops of water of radius (r) 0·085-0·26 cm., exposed to an increasing electric field, horizontal or vertical, first become elongated (for this in the case of the largest drops a field of at least 5000 V/cm. is required), and when the field strength rises to $3875/\sqrt{r}$ V/cm., unstable. A filament then forms at each end, much larger at the positive, and a discharge passes, a glow or spark being visible in the dark, the luminous effects being such as are characteristic of positive or negative point discharges; the current first passing is of the order of 20 microamperes. When the discharge passes small drops pass away from the filament, thus reducing the size of the drops. In this way the maximum size of drops in a thunderstorm would be limited, as *e.g.*, no drop of $r > 0{\cdot}15$ cm. can persist in a field of 9800 V/cm. Reduction of pressure, unless near such as causes a spark to pass in absence of a drop, has no effect.

PA 35-1318

M-2. Magarvey, R. H.

3773. Magarvey, R. H., Stain method of drop-size determination, *J. Meteor.* 14, 2, 182-184, Apr. 1957.

The size spectrum of rain drops in natural rain has been studied by many workers by catching raindrops on absorbent filter paper. The present research deals with the empirical determination of the relationship between the size of the stain on the absorbent paper and the diameter of the raindrop causing it. Simple theory suggests a functional relationship between drop diameter D and stain diameter S of the form: $D = a\,S^b$, in which b has the value 2/3. By the present experiments the actual value of b was found to be 0.75 for drops of greater than 1.5 mm, and 0.93 for drops of less than 1.5 mm. The value of a was found to be 1/3.

Streams of drops with high degree of size uniformity were produced with droppers based on the sensitive jet principle (Magarvey and Taylor, 1956 A and 1956 B), and photographed at a point, determined stroboscopically, at which the drops assumed a spherical shape. The drops were caught on Whatman no. 2 filter paper, moved transversely to the stream, which was dusted with finely powdered, water soluble, blue, aniline dye. The intercepted drops left a permanent blue stain on the paper. Stains were obtained from drops of 50 different sizes, varying from 0.5 to 10.5 mm in diameter.

AMR 10-3773

M-3. Magarvey, R. H., and L. E. Outhouse

1888. Magarvey, R. H., and Outhouse, L. E., Note on the break-up of a charged liquid jet, *J. Fluid Mech.* 13, 1, 151-157, May 1962.

The disintegration of an electrically charged liquid jet is examined. In contrast to an uncharged jet, the main stream is drawn into a series of long thin filaments as a result of the surface energy component arising from the electrical charge. The jet breaks up by a vigorous whipping action, segments of the jet separating at the point of maximum displacement to form a series of near horizontal filaments. These filaments subsequently break up into drops having a range of sizes.

With large streams greater surface charges tend to rupture the surface rather than displace the entire mass.

AMR 16-1888

M-4. Magarvey, R. H., and B. W. Taylor

1152. Magarvey, R. H., and Taylor, B. W., Apparatus for the production of large water drops, *Rev. sci. Instrum.* 27, 11, 944-947, Nov. 1956.

Drop generators are described for the production of streams of drops the equivalent diameters of which are between 0.5 and 20 mm. The generators are based on the principle of the interrupted jet as described by Lord Rayleigh, who found that the kind of disturbance that produced the greatest regularity in resolution was one which impressed upon the jet undulations of length approximately 4½ times the diameter. Two types of droppers based on this principle are described. In one an oscillator-driven earphone is used as the vibrating unit, in conjunction with hypodermic needles of 0.5 to 1.5-mm inside diam, yielding drops of 0.3 to 2.5-mm diam at a maximum production rate of about 400/sec. In the other, a spring-loaded plunger driven by a motor equipped with variable-speed drive is the source of vibrations; diacharge tubes of 7 to 12-mm diam are used, yielding drops up to 15-mm diam, at a rate of up to 20/sec.

Advantages and disadvantages of drop production by these methods are discussed, and data given showing a high degree of uniformity of drop size. Accurate size control and size determination are discussed relative to the execution of experiments designed to measure the physical properties of drops during free fall. In order to study the instability and breakup of large drops, reasonably well-formed drops are produced with large equivalent diameters, which would be difficult to produce by any other means. The behavior of large drops during free fall is concerned with theories of drop-size distribution in natural rain. AMR 10-1152

M-5. Magarvey, R. H., and B. W. Taylor

1110. FREE FALL BREAKUP OF LARGE DROPS.
R.H.Magarvey and B.W.Taylor.
J. appl. Phys., Vol. 27, No. 10, 1129-35 (Oct., 1956).

The breakup of large water drops during free fall is of importance to meteorologists. Theories of precipitation lean heavily on drop multiplication resulting from the shattering of large drops. An experiment is described in which the actual breakup of large drops is observed, and data obtained from which the mechanism of break may be inferred. Drops in the various stages of disintegration have been photographed and the size distribution of fragments noted. A large drop falling freely through the air deforms, inflates somewhat in the same manner as a parachute and bursts with considerable violence. The origin of various size groups of fragments and its significance in determining the observed size distribution has been noted. An experimental arrangement is described that permits a large number of photographs to be taken of all stages of disintegration.

PA 60-1110

M-6. Magarvey, R. H., and B. W. Taylor

4867. SHATTERING OF LARGE DROPS. R.H.Magarvey and B.W.Taylor.
Nature (London), Vol. 177, 745-6 (April 21, 1956).

When falling through the air drops larger than 12 mm are shown by high-speed photographic techniques to flatten, and the centre of the flattened drops then to bulge upwards and open (in the manner of a parachute) before finally rupturing into a shower of smaller droplets. PA 59-4867

M-7. Mahrous, M. A.

1325. The development of a multi-flash camera and its application to the study of liquid jets. M. A. Mahrous. *Brit. J. appl. Phys.*, 3, 329-31 (*Oct.*, 1952).
An apparatus to operate a micro-flash tube a number of times in rapid succession is described and applied to obtain cinematograph pictures of a water-jet at a number of stations along its length. As the speed of efflux is increased, three stages in the form of the jet may be discerned in which (i) the jet becomes varicose, (ii) it becomes sinuous and (iii) pieces are sheared off the sides by friction with the air. It appears that, below speeds of the order 20 m/sec, the liquid always breaks into pieces of a size comparable with the width of the jet. Subsequent break-up of individual drops into smaller units occurs owing to their high speed through the air.

PA 56-1325

M-8. Manea, C. I., M. Stratulat, and S. D. Munteanu

"An Installation for Studying the Spraying of Liquid Fuels at Variable Pressures and Temperatures" (in Roumanian), Studii si Cercetari Energetica, Inst. Energetica, Acad. Repub. Pop. Romine (B) 12, No. 3, 317-327, 1962.

M-9. Mani, J. V. S., and M. N. Rao

505. Mani, J. V. S., and Rao, M. N., Atomization by pressure nozzles (in English), *J. Sci. Engng. Res., India* **1**, 1, 113-118, Jan. 1957.

This is a progress report on an extensive investigation on the various aspects of atomization of fluids, dealing with the drop-size distribution of sprays produced by swirl-type nozzles. Liquified naphthalene was used as liquid; on being sprayed the naphthalene solidifies, and the resulting globules are sized by sieving. Layout of apparatus, with electric heating, and the swirl-type nozzle are illustrated and described. Runs were made at 60, 80, 100 and 120 psig pressure with the liquid at 120 C. The sieving results were plotted as cumulative weight percent on a probability scale, versus square root of drop diameter; straight line relations were found.

Further experiments on the influence of density, viscosity, and surface tension are planned. Authors cite the previous work of V. Srinivas, V. Subba Rao, and M. Narasinga Rao, and also the treatise of E. Giffen and A. Muraszev "The atomization of liquid fuels."

AMR 13-505

M-10. Mani, J. V. S., and M. N. Rao

"Atomization by Pressure Nozzles. III.," J. V. S. Mani, and M. Narasinga Rao (Indian Inst. Technol., Kharagpur). Trans. Indian Inst. Chem. Engrs. 9, Pt. 2, 10-13 (1956/57) (Pub. 1958); ibid. 8, Pt. 2, 151 (1955/56).

CA 53-14597h

M-11. Mani, J. V. S., S. D. Nigam, and M. N. Rao

"Atomization by Pressure Nozzles. IV., J. V. S. Mani, S. D. Nigam, and M. Narasinga Rao (Indian Inst. Technol., Kharagpur). Trans. Indian Inst. Chem. Engrs. 12, 39-56 (1959-60)

CA 55-22951e

M-12. Manson, N., S. K. Banerjea, and R. Eddi

13923* Apparatus for the Microphotographic Study of the Atomization of Liquid Fuels. **Dispositif pour l'étude microphotographique de la pulvérisation de combustibles liquides.** (French.) N. Manson, S. K. Banerjea, and R. Eddi. *Recue de l'institut français du pétrole et Annales des combustibles liquides*, v. 10, no. 6, June 1955, p. 636-656.
Structure of sprays; construction of a device to take and interpret microphotographs of the sprays produced by industrial injectors or burners; experiments with injectors for turbojets. Photographs, diagrams, tables, micrographs, graphs. 15 ref.

BMI 4-13923

M-13. Marshall, W. R., Jr.

1271. Marshall, W. R., Jr., Heat and mass transfer in spray drying, *Trans. ASME* **77**, 8, 1377-1386, Nov. 1955.

Heat and mass-transfer phenomena to and from droplets during spray drying are discussed. Evaporation from pure liquid drops and drops with solids present, in quiescent and in moving air, is considered. The problem of evaporation at high air temperatures is noted. Times of evaporation and temperatures of evaporating drops are treated and formulas given. An attempt is made to compute the over-all rate of evaporation for a spray of drops, and the time variation in mean diameter of the spray, based on Probert's work.

It appears to be generally true that spray drying produces spherical particles which are more or less hollow, depending on the material and on certain operating variables; solid particles are the exception. Duffie and Marshall suggested several causes for the hollowness in spray-dried materials. The bulk density of spray-dried goods is an important factor, influencing the size and cost of storage bins, the type of containers, shipping cost, and marketing requirements. Bulk density depends also on particle size and size distribution, the temperature of the drying air, feed concentration, feed temperature, and direction of air flow. Counterflow air produces somewhat denser particles than does concurrent flow of air.

The question of air flow in spray driers is a most important aspect of the spray-drying process, which merits considerable further research.

AMR 9-1271

M-14. Marshall, W. R., Jr.

6261 **Atomization and Spray Drying.** W. R. Marshall, Jr. Chemical Engineering Progress Monograph Series, No. 2, v. L, 122 p. 1954. American Institute of Chemical Engineers, New York. (TP363 M35a)

Capacity characteristics, spray distribution, and power requirements; drop-size-distribution data and characteristics; droplet evaporation; spray-dried products, dryer design, performance, and costs.

BMI 4-6261

M-15. Marshall, W. R., Jr., and E. Seltzer

Principles of Spray Drying. W. R. Marshall, Jr. (Univ. of Wisconsin) and Edward Seltzer. Chem. Eng. Progress, Vol. 46, No. 10 (Oct 1950), pp. 501–508 and Vol. 46, No. 11 (Nov. 1950), pp. 575–579, 13 fig., 30 ref., discussion.

Comprehensive treatment of spray drying, its history, advantages, disadvantages; pressure atomization, two-fluid atomization (Nukiyama and Tanasawa), rotating disk atomization (with mathematical treatment); spray-gas mixing. Design aspects: operating variables, particle size distribution, bulk density, selection of method of atomization, proper feed concentration, drying temperature, cooling, product removal, spray dryer performance, economic considerations.

deJ I-218

M-16. Mascolo, R. W.

Hydrodynamic Studies of the Effect of Entrained Gases on Injection and Atomization. Richard W. Mascolo (Rocketdyne Division of North American Aviation, Inc., Canoga Park, Calif.). Report R-1466, 5. June 1959, pp. 69 + IV, 28 fig. 38 ref.

Investigation on fundamental injection characteristics of liquids in injector configurations used in rocket engines, with emphasis on effect of entrained gas on upstream flow conditions, injection, and atomization. Test stand and research techniques are described; previous literature is surveyed. Initial data were obtained with water. Found that an orifice, drilled at an angle of 70 deg. to the injector face, produces not cylindrical, but a wide and flat jet with distortion increasing with distance from injector face. Impingement of two such jets is irregular and not easily controlled. Injection of a single gas bubble through one of a pair of orifices produces a wave disturbance in the atomization pattern downstream from the impingement point; one or two cycles in the frequency range from 3000 to 7000 cps. have been observed. Injection of larger amounts of gas tends to diffuse the pattern and create a region of more homogeneous and finely divided particles. Instrumentation is fully described; typical spray photographs are shown; method of data reduction is explained. Researches of Castlemen, Lee, Haenlein, Northup, Rupe, Knapp and Hollaender are cited. Work of Plesset and Zwick, Dergarabedian, Trilling, and Osbourne on bubble collapse are discussed.

deJ II-281

M-17. Mason, B. J.

30910 THE COLLISION, COALESCENCE, AND DISRUPTION OF DROPS. B. J. Mason.
Endeavour (GB), Vol. 23, 136-41 (Sept. 1964).

The behaviour of two drops as they approach each other in a dispersion medium is important in rain clouds, in aerosols, and in such processes as distillation and condensation. This article discusses theoretical studies of the relevant factors, and it also describes experimental techniques that have been designed to investigate the problem with the help of photography.

PA 67-30910

M-18. Mason, B. J., O. W. Jayaratne, and J. D. Woods

14132 AN IMPROVED VIBRATING CAPILLARY DEVICE FOR PRODUCING UNIFORM WATER DROPLETS OF 15 TO 500 μm RADIUS.
B.J.Mason, O.W.Jayaratne nd J.D.Woods.
J. sci. Instrum. (GB), Vol. 40, No. 5, 247-9 (May, 1963).

A vibrating capillary device, consisting of a hypodermic needle vibrated at its resonant frequency by an electromagnetically driven diaphragm, produces controllable and very uniform streams of drops of radius down to 15 μm. The size and frequency with which the droplets are produced depend upon the flow rate of the liquid through the needle, the needle diameter, its resonant frequency and the amplitude of oscillation of the needle tip. The device is being used to study the collision and coalescence of small water drops in air.

PA 66-14132

M-19. Masugi, N. I.

"Theoretical and Experimental Study of the Deformation and Atomization of a Liquid Drop in a High-velocity Air Stream," Amer. Rocket Soc. Preprint 355-56 (1956)

M-20. Mathews, J. B., and B. J. Mason

"Electrification Produced by the Rupture of Large Water Drops in an Electric Field," Quart. J. Roy Met. Soc. (GB) 90, No. 10, 275-86 (Oct. 1964)

M-21. Maxwell, R. W.

"Study of Air Atomization," Mass. Inst. Tech., M. S. Thesis, May 21, 1948

M-22. May, K. R.

"A New Graticule for Particle Counting and Sizing," J. Scientific Inst. 42, 500-1 (1965)

M-23. May, K. R.

The "May Spray," a Small Two-Fluid Atomizer. K. R. May (Microbiological Res. Establ., Porton, Wilts., Engl.). M. R. E. D. Note No. 48, Feb. 1960, 12 p., 7 fig., 4 ref.

Describes a two-fluid nozzle, in which an annular air orifice (fed by a compressor) surrounds a central cylindrical nozzle connected to the liquid supply; the liquid is sucked up to the nozzle by the depression created by the air-flow. Eleven nozzles are connected to a cylindrical body, having passages for the air, and for the liquid. This multiple unit gives finer spray than a single nozzle having the same capacity. Nozzle is shown in sectional drawings; complete unit is shown in picture; air and liquid consumption is shown in graphs; droplet spectrum is given.

deJ II-286

M-24. May, K. R.

Uniform Drops from the Vibrating Reed System. K. R. May (Microbiological Res. Establ., Porton, Wilts., Engl.). MRED Note No. 50, Oct. 1960, 2 p., 2 fig.

Describes improvement on the vibrating-reed device for producing uniform droplets, described in WOLF 1958. The tip of the reed is bent downwards so that it dips into the liquid surface in the direction of its axis. Drop size can be varied (in the range of 50 to 400 microns) by a Variac placed into the electromagnet circuit. Means for ensuring constant liquid level, and producing sharp, clean tip (which is necessary for producing small drops of 5 micron or less) are described. Cited in WOLF 1961.

deJ II-286

M-25. May, K. R.

1540. An improved spinning top homogeneous spray apparatus. K. R. MAY. *J. Appl. Phys.*, 20, 932–8 (*Oct.*, 1949).

An apparatus is described which produces homogeneous mists or clouds of solid particles of any desired size. Liquid is sprayed by a Beams high-speed air-driven top, using a property of high-speed air films so that automatic extraction of unwanted satellite droplets, better running characteristics over a wider range, simplified construction and low air consumption are obtained.

PA 53-1540

M-26. May, K. R.

"The Cascade Impactor: An Instrument for Sampling Course Aerosols," J. Sci. Instr. 22, 187-95 (1945)

M-27. Maybank, J., et al.

1288. Maybank, J., Fenwick, W. J., and Cuthbertson, K. J., A magnetically stabilized spinning disk apparatus for homogeneous aerosol production, *Defence Research Board, Canada* Pap. no. 165, 4 pp., Oct. 1956.

A spinning disk apparatus which produces nearly homogeneous aerosols is described. The disc is stabilized by eddy currents set up in it by an electromagnet. The braking action of the magnet makes it possible to operate the disc at low speeds, and use driving air at a pressure sufficiently high for removing the satellite droplets. The droplet diameter of the liquid aerosol produced can be varied from 10 to 200 microns, the coefficient of variation of the diameter of a given aerosol being approximately 3 to 5 per cent. The liquid feed rate may be varied from 0.5 to 2.0 cu cm per min. The apparatus is fully described, showing the outside appearance, a sectioned drawing, and the electromagnet circuit. Samples of photographs of droplets, using dibutyl phthalate liquid are shown having remarkable uniformity; the diameters vary from 30 to 270 microns depending on the angular velocity of the disc.

AMR 10-1288

M-28. Mayer, E.

3679. Mayer, E., Theory of liquid atomization in high velocity gas streams, *ARS J.* 31, 12, 1783–1785 (Tech. Notes), Dec. 1961.

Liquid atomization by high-velocity gas streams is investigated analytically by considering the behavior of gas-liquid interface in the regime of capillary wave (ripple) propagation. With given fluid properties (density of liquid and of air, surface tension and viscosity of liquid) and wind velocity relative to liquid velocity, all wavelengths exceeding a minimum value will grow at an exponential rate characterized by a time modulus dependent on the wavelength and on fluid parameters. At a certain value of the wind-induced wavelength the crest of the wave is shed as a ligament from which droplets are formed whose diameter is also proportional to the wavelength. By consideration of the steady-state droplet formation rate on a large liquid surface, an expression is derived for the droplet size distribution function, which yields a formula for the average droplet size obtained on primary atomization. This is in satisfactory agreement with previously found empirical correlations. A numerical example is worked out.

This paper is primarily concerned with atomization under conditions prevailing in turbojets and ramjets, but the treatment has applicability also for other technical fields.

AMR 15-3679

M-29. McCormack, P. D., L. Crane, and S. Birch

11847 AN EXPERIMENTAL AND THEORETICAL ANALYSIS OF CYLINDRICAL LIQUID JETS SUBJECTED TO VIBRATION.
P. D. McCormack, L. Crane and S. Birch.
Brit. J. Appl. Phys., Vol. 16, No. 3, 395–408 (March 1965).

It is established that the Rayleigh-Weber capillary type instability on liquid jets may be triggered by velocity modulation at the injector. It is shown that by application of mechanical vibration in the appropriate frequency range, such velocity modulation can be induced. A second-order analysis is developed to cover the case of very small initiating modulation amplitudes. With finite velocity modulation it is demonstrated that considerable liquid bunching occurs which results in the formation of disks on the jet. A modified Rayleigh analysis is carried out which qualitatively covers characteristics observed in the region of finite velocity modulation. Vibration acceleration values of 200 g and more were found necessary to enter the region where the liquid bunching mechanism predominates over the surface tension mechanism.

PA 68-11847

M-30. McCubbin, T. K.

845. The particle size distribution in fog produced by ultrasonic radiation. T. K. McCubbin, Jr. Letter in *J. Acoust. Soc. Amer.*, 25, 1013–14 (*Sept.*, 1953).

The author describes fog produced by 2·4 Mc/s sound generated in water and focused on the upper surface. With soap in the water no fog appears. Fog particle diameters, determined by microscope, are grouped around 4 to 5 microns.

PA 57-845

M-31. McEntee, F. J., Jr.

6062 **Methods of Atomization in Spray Drying.** Frank J. McEntee, Jr. *Industrial Heating*, v. 19, Mar. 1952, p. 504-510, 568. (A condensation.)

The common methods of atomization used in spray-drying systems for breaking up a fluid into very small dispersed droplets which can be rapidly dried are described. A brief review of the 4 basic operations involved in spray drying is included and several types of atomizing devices in commercial use are discussed

BMI 1-6062

M-32. McIrvine, J. D. B.

ATOMIZATION OF VISCOUS LIQUIDS
WITH SWIRL-CHAMBER PRESSURE NOZZLES

(Publication No. 24,307)

John Douglas Bruce McIrvine, Ph.D.
The University of Wisconsin, 1957

Supervisor: Professor William Robert Marshall, Jr.

Atomization of liquids, solutions, and suspensions is an important aspect of the operation of spray drying, combustion, and humidification and water-cooling equipment. In spray drying in particular, the physical properties of the liquid may be very different from the properties of water. One commonly-used method of atomization is by means of swirl-chamber pressure nozzles. Data on the performance characteristics of flow rate, spray cone angle, pressure required for the initial attainment of a conical spray, spatial weight distribution, and drop-size distributions are available only for limited variations in liquid properties. The objectives of this work were to obtain fundamental correlations by which these characteristics could be related to the liquid viscosity and the nozzle dimensions.

The nozzles studied were designed after considerations made of superimposed free-vortex and radial inward flow patterns, which yielded a swirl chamber contoured in the shape of a logarithmic spiral.

As the Newtonian viscosity increased, the spray cone angle was found to decrease, the pressure required for formation of a fully developed conical spray increased greatly, and the spray drop size increased. The discharge coefficient was found to increase in some cases, to decrease in others, and to exhibit a maximum flow as viscosity increased for yet others; the various behaviors being present in different ranges of values of the ratio of inlet to orifice area of the nozzle.

Consideration of vortex theory showed that nozzle operation was not a pure free vortex, since the pressure drop measured across the swirl chamber was not as large as that across a corresponding free vortex. Extension of vortex pressure-gradient relations to a case with variable exponent on radius, and combination of the integrated pressure drop with the discharge coefficient definition yielded a relation which predicted the discharge coefficient to be a function of air-core radius, the ratio of swirl-chamber-inlet to orifice area, and the exponent on radius in the vortex pressure-gradient relation. This was used as the basis for a correlation of the discharge coefficient data from the experimental nozzles against the ratio of inlet to orifice areas.

Flow through the nozzles was found to be proportional to pressure to an exponent which was significantly less than 0.50, the exponent increasing with orifice radius and passing through a minimum as viscosity increased.

The spray volume-drop size distributions from the nozzles were measured from an average of over 9,000 drops per determination. The distributions were found to give median diameters which were linearly related to the Sauter mean diameter (the volume:surface-ratio-weighted mean diameter) and the volume-weighted mean diameter. The standard deviations of the distributions were a function of the median diameter only.

The sample-capture method of spray analysis was tested by comparing results obtained with it and results obtained on identical nozzles by impaction methods and by spray-cooling of wax. The results agreed well in the case of the impaction method; and in the spray-cooling method showed results similar to those obtained with capture methods at greater distances from the orifice.

Empirical correlations of cone angle, mean drop size, and discharge coefficient were made which should be of use in choosing or designing swirl chamber nozzles for performance to give specified behavior with liquids of various viscosities. The results could also be used to predict the influence of variation of liquid viscosity on performance of existing nozzles. The empirical correlations appeared unsuited for extrapolation outside the range of dimensions, performance characteristics, and liquid viscosity over which they were made. 457 pages. $5.85. Mic 57-4080

DA 17-2540

M-33. Mehlig, H.

Verfahren zur Messung der mittleren Zerstäubungsfeinheit von Brennstoffen für Dieselmotoren (Method for measuring the average fineness of atomization of Diesel engine fuels). H. Mehlig. Z. Techn. Phys. (Germ.), Vol. 15 (1934), p. 360.

deJ I-224

M-34. Mehlig, H.

Zur Physik der Brennstoffstrahlen in Dieselmaschinen (Physics of f prays in Diesel engines). H. Mehlig. Automobiltechn. Zeitschrift (ATZ) (G Vol. 37 (Aug. 1934), pp. 411–421, 21 fig.

Uses results of earlier investigators to show that penetrations for plain hole nozzles at various orifice diameters, fuel injection and airchamber pressures can be predicted when the penetration for one set of these variables is known. Mean drop-size determinations at various distances from the spray axis by photometric means similar to Sauter's in chamber at various air pressures and various air motions. Concludes that mean drop diameter is affected more by air turbulence than by any other factor.

deJ I-223

M-41. Miesse, C. C.

3420. Miesse, C. C., The combustion of atomized liquid propellants, Amer. Chem. Soc. Prepr., 129th Ann. Meet., Dallas, Tex. Apr. 1956, 29 pp. + 16 figs.

The applicable theoretical and experimental papers on atomization, evaporation, and combustion of liquid propellants are summarized and applied to the problem of the combustion of atomized liquid propellants. The available reports on ignition delay, performance, and stability limits for liquid-propellant combustors are then reviewed, and the data correlated in accordance with the experimental data and theoretical concepts summarized above. The results of the survey indicate that more rapid ignition, higher performance, and lower stability limits are achieved by fine atomization, and that the effects of unstable combustion and erosive burnout of combustion chamber walls are minimized by coarser atomization. Several atomization criteria for optimum performance are proposed as a consequence of this investigation.

Conclusions: The established correlations and laws of atomization and evaporation are directly applicable to the various combustion problems of ignition delay, performance, stability limits, and design. Experimental and theoretical information obtained from a study of the single droplet are of great value in understanding the behavior of sprays, and the combustion of sprays in general. Ignition delay, performance, and stability limits can all be considered with respect to the quantity of vapor available for combustion, and can, therefore, be explained in terms of the initial atomization and subsequent evaporation of the liquid propellants. The limited quantity of precise knowledge in this important field should serve to stimulate an extended investigation of the phenomena involved.

AMR 9-3420

M-42. Miesse, C. C.

793. Miesse, C. C., The effect of ambient pressure oscillations on the disintegration and dispersion of a liquid jet, *Jet Propulsion* 25, 10, 525-530, 534, 15 figs, 9 refs., Oct. 1955.

The effect of ambient pressure oscillations on the disintegration and dispersion of a liquid jet was investigated by imposing a high-intensity acoustic field on the jet. The experimental set is described whereby a transversal and a longitudinal oscillating sound pressure can be produced. The effect of sound pressure, directed perpendicularly to the stream, was to disperse the droplets in a diverging sinusoidal configuration; the effect of an axial cavity resonance directed parallel to the stream was to coalesce the droplets, as a consequence of the velocity variation of successive fluid particles. Each of these effects was analysed theoretically; it was found that the magnitude of each effect decreased with an increase either in the velocity of the stream or in the frequency of the imposed oscillation.

The theoretical and experimental work, while treated with considerable generality, is specifically directed to the clearing up of phenomena in a liquid-propellant rocket combustion chamber. The following main conclusions have been drawn: (1) Ambient pressure oscillations, either normal to or parallel to the axis of liquid jet, tend to decrease the length of the solid stream and have a decided effect on the dispersion pattern of the jet. (2) It can be shown both experimentally and theoretically that the magnitude of this effect decreases as either the pressure drop across the orifice or the frequency of the pressure oscillations is increased. (3) Transverse pressure waves aid considerably in the mixing of parallel streams. (4) The coalescence of the droplets, which result from axial pressure oscillations in the chamber, can lead to unstable combustion if the steady-state flow velocity is less than a certain critical value. For the thorough understanding of this paper, a study of the previous paper of the same author is recommended ["Correlation of experimental data on the disintegration of liquid jets," *Indust. Engng. Chem.* 47, 9, 1690-1701, Sept. 1955].

AMR 9-793

M-43. Miesse, C. C.

From Liquid Stream to Vapor Trail. C. C. Miesse (Aerojet-General Corp.). Proc. 1955 Gas Dynamics Symp. at Northwestern Univ., Multicopy Corp. Evanston, Ill. pp. 7-26, 15 fig., bibl. with 119 titles.

Experimental correlations and theoretical analyses of phenomena occuring in the transformation of a liquid stream into a vapor trail are summarized and applied to available experimental data. For the initial processes of jet disintegration, drop formation, and secondary atomization, it is found that the phenomena are characterized chiefly by the Weber Number, with viscosity effects being accounted for by the Reynolds Number. Effect of relative velocity on the evaporation and combustion of a drop is represented by the Schmidt and Reynolds Numbers, and the ballistics of an evaporating or burning drop is strongly dependent upon the ratio of the kinematic viscosity of the air to the evaporation or combustion rate of the drop. Limited experimental data on temperature profiles in the exhaust jet indicate that data can be correlated by applying the results of theoretical analysis to the measured temperatures and distances, relative to the temperature and diameter, respectively, at the exhaust nozzle. The unsolved problems are outlined and several methods for determining the resultant size distribution of the drops are discussed. Disintegration of liquid stream; droplet formation; secondary atomization and coalescence; evaporation and ballistics; combustion; the vapor trail. Conclusions: (1) the isotherms and isovols in the exhaust jet of a sonic nozzle can be correlated in terms of distance relative to throat diameter of nozzle, (2) research is needed on the phenomena of jet impingement, coalescence, and size distribution, as dependent on the properties of the liquid jet and its surrounding atmosphere.

deJ I-227

M-44. Miesse, C. C.

184. Miesse, C. C., Correlation of experimental data on the disintegration of liquid jets, *Indust. Engng. Chem.* 47, 9 (part I), 1690-1701, Sept. 1955.

For the combustion of fuel sprays, as it occurs in internal combustion engines, in gas turbines, and in liquid-propellant rockets, the disintegration of the liquid jets is of fundamental importance. During the past hundred years a large number of experimental researches have been made on sprays, and numerous attempts were made to correlate the experimental results by means of theoretical analyses, based on fundamental properties of the liquids and the surrounding medium. Author analyzes a number of these existing theories, namely those of Rayleigh, Weber, and Tomotika, which are based on the small disturbance of a liquid jet surface, influenced by the surface tension of the liquid, its viscosity, its kinetic energy, and hydrodynamic velocity potential. Tomotika considered the viscosity ratio to be of prime importance, and produced useful correlations for low-velocity jets. Author then analyses the work of Tyler, Holroyd, Littaye, and others whose endeavor was to correlate the secondary atomization

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3420. Miesse, C. C., The combustion of atomized liquid propellants, Amer. Chem. Soc. Prepr., 129th Ann. Meet., Dallas, Tex. Apr. 1956, 29 pp. + 16 figs.

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AMR 9-3420

M-42. **Miesse, C. C.**

793. Miesse, C. C., The effect of ambient pressure oscillations on the disintegration and dispersion of a liquid jet, *Jet Propulsion* 25, 10, 525-530, 534, 15 figs, 9 refs., Oct. 1955.

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AMR 9-793

M-43. **Miesse, C. C.**

From Liquid Stream to Vapor Trail. C. C. Miesse (Aerojet-General Corp.). Proc. 1955 Gas Dynamics Symp. at Northwestern Univ., Multicopy Corp. Evanston, Ill. pp. 7-26, 15 fig., bibl. with 119 titles.

Experimental correlations and theoretical analyses of phenomena occuring in the transformation of a liquid stream into a vapor trail are summarized and applied to available experimental data. For the initial processes of jet disintegration, drop formation, and secondary atomization, it is found that the phenomena are characterized chiefly by the Weber Number, with viscosity effects being accounted for by the Reynolds Number. Effect of relative velocity on the evaporation and combustion of a drop is represented by the Schmidt and Reynolds Numbers, and the ballistics of an evaporating or burning drop is strongly dependent upon the ratio of the kinematic viscosity of the air to the evaporation or combustion rate of the drop. Limited experimental data on temperature profiles in the exhaust jet indicate that data can be correlated by applying the results of theoretical analysis to the measured temperatures and distances, relative to the temperature and diameter, respectively, at the exhaust nozzle. The unsolved problems are outlined and several methods for determining the resultant size distribution of the drops are discussed. Disintegration of liquid stream; droplet formation; secondary atomization and coalescence; evaporation and ballistics; combustion; the vapor trail. Conclusions: (1) the isotherms and isovels in the exhaust jet of a sonic nozzle can be correlated in terms of distance relative to throat diameter of nozzle. (2) research is needed on the phenomena of jet impingement, coalescence, and size distribution, as dependent on the properties of the liquid jet and its surrounding atmosphere.

deJ I-227

M-44. **Miesse, C. C.**

184. Miesse, C. C., Correlation of experimental data on the disintegration of liquid jets, *Indust. Engng. Chem.* 47, 9 (part II), 1690-1701, Sept. 1955.

For the combustion of fuel sprays, as it occurs in internal combustion engines, in gas turbines, and in liquid-propellant rockets, the disintegration of the liquid jets is of fundamental importance. During the past hundred years a large number of experimental researches have been made on sprays, and numerous attempts were made to correlate the experimental results by means of theoretical analyses, based on fundamental properties of the liquids and the surrounding medium. Author analyzes a number of these existing theories, namely those of Rayleigh, Weber, and Tomotika, which are based on the small disturbance of a liquid jet surface, influenced by the surface tension of the liquid, its viscosity, its kinetic energy, and hydrodynamic velocity potential. Tomotika considered the viscosity ratio to be of prime importance, and produced useful correlations for low-velocity jets. Author then analyzes the work of Tyler, Holroyd, Littaye, and others whose endeavor was to correlate the secondary atomization of liquid drops by means of reasoned conjectures, such as the assumption that the breakup of the drops occurs when the drag forces exceed the inertia forces. Finally, the author analyses the investigations based on dimensional analysis of Ohnesorge, Baron, Haenlein, Borodin and Dityakin, Probert, and others.

After all this searching study, possibly one of the most penetrating in recent years, author comes to the conclusion "that the total problem of jet integration, which results in a measurable distribution of droplet sizes, is by no means solved, nor are the related problems of droplet ballistics and evaporation, or combustion. Outstanding among the missing links are the effects caused by the properties of the ambient atmosphere: density, relative velocity, viscosity, pressure, and temperature. . . Nor have the problems of secondary atomization, droplet-size distribution, combustion effects, and properties of jet bundles been solved satisfactorily. A wide-open field has been left for future theoretical research."

AMR 9-184

M-45. Miesse, C. C.

3770. Miesse, C. C., The effect of a variable evaporation rate on the ballistics of droplets, Ann. Meet. Amer. Rock. Society, Cleveland, O., Sept. 19-21, 1955, Pap. 223-55, 14 pp. + 6 figs.

In order to allow for the effect of the variation of evaporation rate of a liquid droplet with its Reynolds number on its velocity and diameter variations, the present analysis considers the ballistics and evaporation (Froessling's) simultaneously. The resulting nonlinear equation yields analytical solutions for discrete values of the viscosity to still-air evaporation-rate parameter, which permit ready determination of the variation of drop size and relative velocity with time and distance. The results indicate that the constant-evaporation-rate analysis is valid for large values of the parameter mentioned above, but should be modified for smaller values. Numerous illustrative curves are presented, and the analysis is applied to available experimental data.

Conclusions: (1) The ballistics of a liquid droplet injected into a uniform air stream can be determined analytically for several values of the ballistics parameter, by simultaneous solution of the evaporation and ballistics equations; (2) the effect of the increase of evaporation rate due to relative velocity is that both the distance traveled and droplet lifetime are reduced; (3) relative velocity effects produce a considerable change in the drop-size curves.

AMR 9-3770

M-46. Miller, K. D.

12412 DISTRIBUTION OF SPRAY FROM IMPINGING LIQUID JETS. K.D.Miller, Jr.
J. appl. Phys., Vol. 31, No. 6, 1132-3 (June, 1960).

An improvement is made in the treatment of this problem by Rans (Abstr. 931 of 1960). The new formulae agree better with experiments on the circumferential distribution of flow in the resultant spray. Both treatments use an "ideal fluid" model.

PA 63-12412

M-47. Mina, F. A.

"Ultra-low-pressure Aerosols." Francis A. Mina (Zonite Products Corp., New Brunswick, N. J.). Modern Packaging 27, No. 11, 176-8, 242-4 (1954).

CA 48-14045c

M-48. Misek, T.

"Breakup of Drops by a Rotating Disk." T. Misek (Vyzkumny Ustav, Kralovopolska Strojirna, Prague). Collection Czech. Chem. Commun. 28, 426-35 (1963).

CA 58-12193e

M-49. Mock, F. C., and D. R. Ganger

Practical Conclusions on Gas Turbine Spray Nozzles. F. C. Mock and D. R. Ganger (Bendix Products Div., Bendix Aviation Corp.). SAE Quart. Trans., Vol. 4 (1950), pp. 357–367, 17 fig. Abstract: SAE Jl., Vol. 58 (Feb. 1950), pp. 22–25, 6 fig.

Investigates applicability of the swirl type nozzle and the duplex nozzle for gas turbine power plants. Examines atomization from these nozzles, and discusses three steps of atomization: (a) "bubble" or "olive" form, (b) glassy cone and (c) complete atomization. Concludes that the swirl nozzle is inadequate for the needs of the turbine engine at low fuel rates and suggests use of the duplex nozzle. Photographs, curves, and diagrams are given in support of these conclusions.

deJ 1-333

M-50. Monk, G. W.

3351. Viscous energy dissipated during the atomization of a liquid. G. W. Monk. Letter in *J. Appl. Phys.*, 23, 288 (*Feb.*, 1952).

Assuming the droplets formed from a liquid thread, a rough calculation of viscous energy dissipated in producing the thread is made.

PA 55-3351

M-51. Morrell, G.

5548. Morrell, G., Rate of liquid jet breakup by a transverse shock wave, NASA TN D-1728, 27 pp., May 1963.

Single water jets were exposed to transverse shock waves in a 2.7- by 2.7-inch shock tube equipped with a variable-length high-pressure section. High-speed photographs were taken of the breakup process with backlighting. Analysis of the photographs indicates a monotonic decrease in breakup time with gas velocity and an increase in breakup time with initial jet radius. A theoretical model based on stripping from a liquid boundary layer is developed and gives fair agreement with the experimental data.

AMR 16-5548

M-52. Morrell, G.

N63-15561 National Aeronautics and Space Administration Lewis Research Center, Cleveland, Ohio
RATE OF LIQUID JET BREAKUP BY A TRANSVERSE SHOCK WAVE
Gerald Morrell [redacted] NASA, May 1963 28 p 13 refs
(NASA TN D-1728) OTS: $0.75

The breakup of a single water jet by a transverse shock was studied experimentally in a 2.7- by 2.7-inch shock tube equipped with a variable-length high-pressure section. High-speed backlighted photographs were analyzed to obtain breakup time and liquid deformation. Breakup time decreased regularly with an increase in gas velocity and increased with jet radius. The extent of deformation was a linear function of the ratio of Weber number to the square root of Reynolds number based on initial jet radius. A theoretical model was developed based on stripping from a liquid-phase boundary layer, and an explicit function for breakup time resulted. The calculated breakup times were found to be in fair agreement with the measured values.

N63-15561, 12-11

M-53. Morrell, G.

5114. Morrell, G., Critical conditions for drop and jet shattering, NASA TN D-677, 13 pp., Feb. 1961.

When a liquid drop or jet is subjected to a gas stream exceeding some critical value of velocity, it will disintegrate and break up. This behavior has important effect on combustion, e.g., in rocket engines, where it may cause sudden change in combustion intensity and amplification of pressure waves. A knowledge of the laws governing drop and jet shattering should help in developing a theory of nonlinear oscillatory combustion. Author reviews recent work in this field, by Hanson, Domich and Adams, Rabin and Lawhead, Hinze, Gordon, and others.

Based on the philosophies and results of previous researches, the author presents a generalized model describing the threshold conditions for breakup of jets and drops subjected to a step change in velocity with variable flow duration. For flow durations that are long compared with the natural period of the liquid system, a deformation mechanism is postulated; for flow durations that are short compared with the natural period, a stripping mechanism governed by the tensile properties of the liquid is assumed. The breakup conditions predicted by the theory for an assumed critical displacement are in general agreement with published experimental data.

The main body of the paper is largely theoretical and mathematical, but not too difficult to follow. This paper provides a useful background and framework for the study of the voluminous literature on the subject, which deals with specific aspects, and definite applications, of jet and drop breakup.

AMR 14-5114

M-54. Morrell, G., and F. P. Povinelli

2503. Morrell, G., and Povinelli, F. P., Breakup of various liquid jets by shock waves and applications to resonant combustion, NASA TN D-2423, 12 pp., Aug. 1964.

Authors extend previous work with water [AMR 16(1963), Rev. 5548] to include *n*-heptane, liquid oxygen and glycerol-water mixtures. Theory has been modified since Clark [NASA TN D2424, 1964] showed that liquid jet in crossflow cannot be regarded as flat sheet. Proposed model is not wholly satisfactory, yielding high values for break up times >3 msec and low values for times <1 msec.

With liquid breakup assumed to be rate-controlling process, similarity parameters for rocket combustion instability theories of Penner, Crocco and Priem were evaluated. All three theories indicate that jet radius should be scaled in proportion to 4/3 power of combustor radius and square root of pressure in order to maintain stability similarity.

AMR 18-2503

M-55. Morris, R. T.

"Improved Atomizer for Use in Certain Chromatographic Analysis Procedures." R. T. Morris (Western Regional Research Lab., Albany, Calif.). Anal. Chem. <u>24</u>, 1528 (1952).

CA 47-1434

M-56. Mugele, R. A.

6106. Mugele, R. A., Maximum stable droplets in dispersoids, *AIChE J.* 6, 1, 3-8, Mar. 1960.

This is a condensed account of droplet size distributions, primarily in two-phase sprays. Introducing the concept of a maximum permissable drop size, the author shows that this can be used to correlate available data.

AMR 13-6106

M-57. Mugele, R. A., and H. D. Evans

8551. Droplet size distribution in sprays. R. A. MUGELE AND H. D. EVANS. *Industr. Engng Chem.*, 43, 1317–24 (*June*, 1951).

General features of size distribution are reviewed for dispersed systems. The concepts of "mean diameter" and "distribution parameter" are clarified and generalized. Previous applied distribution equations (Rosin and Rammler, Nukiyama and Tanasawa, log-probability) are examined critically in regard to theoretical soundness and application to spray data. A new equation, called the upper-limit equation, is formulated and proposed as a standard for describing droplet size distributions in sprays. It is based on the differential equation of the Gaussian distribution, the distributed quantity being $y = \ln ax/(x_m - x)$ where a is a dimensionless parameter, x is droplet diameter and x_m is maximum stable diameter. The upper-limit equation is applied to a wide variety of experimental data on sprays and more limited results on other dispersoids. It is concluded that the new equation fits the available spray data accurately, calculates the mean diameters accurately, applies also to emulsions and aerosols when the mechanism of formation is not too different from that of sprays, and indicates the type of distribution function that may be derivable from the basic mechanism of dispersion, when this mechanism is better understood. For a mechanical spray, the relation of the parameters of the distribution equation to physical properties and design variables is indicated.

PA 54-8551

M-58. Muraszew, A.

Continuous Fuel-Injection System with Rotating Fuel Chamber. A. Muraszew. Engng. (Engl.) Vol. 166 (1948), pp. 316–317, 7 fig. Abstract: Continuous Fuel Injection. Mech. Engng., Vol. 70 (1948), p. 1009, 2 fig.

Suggests a gas turbine fuel injection system using a rotating hollow disk with orifices or a slot near its periphery for atomizing the fuel. Centrifugal force provides the injection pressure and the required increase of pressure and flow rate with speed. Fuel supply through the hollow compressor-turbine shaft. Exact matching of the fuel flow to the engine requirements by variation of fuel flow through a metering orifice in the shaft. This varies the thickness of the fuel layer in the hollow rotor and thereby the centrifugal pressure behind the orifices. Refers to experiments at Porton Laboratory which showed that such a device produces drops of uniform size surrounded by very small droplets. Theoretical analysis of fuel discharge and atomization with a worked out example.

deJ I-237

N-1. Narasimhan, M. V., and K. Narayanaswamy

6171. Narasimhan, M. V., and Narayanaswamy, K., Experimental studies on intermittent airblast sprays, *J. Indian Inst. Sci.* 45, 4, 83–108, Oct. 1963.

The atomization of a liquid fuel by an air stream in a continuous spray process depends on a number of factors, the most important being the relative velocity between the fuel and air and the flow ratio. The present study deals with the effect of these factors in intermittent airblast sprays.

The effect of the flow variables, air velocity, volume of air and volume of fuel and nozzle design on spray characteristics were studied. It is concluded from the results that for satisfactory atomization of the fuel the air velocity should be about 700 fps and the flow ratio (fuel to air) between 2000–3000 by volume. The influence of nozzle design on atomization is indicated.

AMR 17-6171

N-2. Nayyar, N. K., and G. S. Murty

8618 THE STABILITY OF A DIELECTRIC LIQUID JET IN THE PRESENCE OF A LONGITUDINAL ELECTRIC FIELD. N.K.Nayyar and G.S.Murty.
Proc. Phys. Soc., Vol. 75, Pt 3, 369-73 (March, 1960).

The stability of a cylindrical jet of incompressible inviscid liquid in the presence of a longitudinal electric field is investigated. It is shown that the electric field increases the stability of the jet. For given values of electric field, the wavelength of the disturbance at which the instability sets in and the wavelength which has maximum rate of instability are calculated.

PA 63-8618

N-3. Needham, H. C.

"Correlation of Particle Size Data on Pressure Jet Atomizers," Power Jets (Research and Development) Ltd., Report No. R1209, 1946.

N-4. Nelson, P. A.

DROP SIZE DISTRIBUTIONS FROM CENTRIFUGAL SPRAY NOZZLES

(L. C. Card No. Mic 59-673)

Paul A. Nelson, Ph.D.
Northwestern University, 1958

Adviser: William F. Stevens

The objective of this investigation was to obtain an insight into the mechanism of liquid break-up from centrifugal pressure nozzles at intermediate pressure levels of 100 to 1500 psi. From theoretical considerations, atomization from centrifugal nozzles appears to be a function of the flow characteristics of the liquid as it leaves the nozzle and independent of the gas medium into which the liquid is sprayed. The flow conditions of the liquid leaving the nozzle can be defined by variables which do not include any nozzle dimension except the orifice diameter on the assumption that all flow peculiarities due to the nozzle design are dumped out by the high turbulence in the flow through the orifice.

With this basic assumption, the air core diameter data of other investigators for grooved-core centrifugal nozzles were correlated by dimensional analysis. For Reynolds numbers above 10,000, the air core-to-orifice-diameter ratio appeared to be a function of the spray cone angle only.

Extensive atomization data were obtained in this investigation by freezing the entire spray in a specially built collector which was cooled by liquid nitrogen. The drop-size distributions obtained by screening the frozen particles fit the square-root-normal frequency function.

The volume median drop-diameter was correlated with dimensionless groups determined by dimensional analysis. The data for all of the runs except those in which water was sprayed were plotted on a single graph with an average deviation of 8.25 per cent from the curve of best fit. This included a total of ninety-seven runs, performed with six organic liquids (range of variables: density, four fold; surface tension, two fold; viscosity, nine fold) with nineteen different nozzles, and over the pressure range, 100 to 1500 psig. The drop-size data for water could not be correlated with the organic data but it agreed well with the data for water of W. H. Darnell (Ph.D. Thesis, Univ. of Wisconsin, 1953) when plotted in a manner similar to that used for the organic liquids.

The square-root-normal standard deviation was correlated for all of the data (organic liquids and water) with dimensionless groups. The average deviation of the data from the curve of best fit was 13.0 per cent.

The fact that the data could be correlated quite well was considered to be evidence that the variables which were chosen adequately define or dictate the drop-size distribution. It is true that the correlations were based on data for one type of nozzle, the grooved-core type. But the variables used in the correlations were properties of the spray rather than properties related to specific types of nozzles. Therefore, the correlation curves might be applicable to other types of centrifugal, hollow cone nozzles.

Microfilm $2.00; Xerox $5.40. 110 pages.

DA 19-2041

N-5. Nelson, P. A., and W. F. Stevens

5113. Nelson, P. A., and Stevens, W. F., Size distribution of droplets from centrifugal spray nozzles, *AIChE J.* 7, 1, 80–86, Mar. 1961.

This paper discusses methods of measuring, expressing, and correlating drop-size data which the authors found useful in their study of grooved-core centrifugal spray nozzles. They emphasize that the distribution functions are not derived from natural laws, but are made to fit experimentally obtained data. They investigate several types of normal distributions, namely (1) log-normal, (2) square-root normal, and (3) upper-limit distribution; the first two are two-parameter, the third a three-parameter function. In present investigation authors found the square-root-normal distribution best adapted to represent the actual data. The experiments were executed by freezing the spray droplets in liquid nitrogen on their emergence from the nozzle and subsequently sieving them through nine sieves. The advantage is pointed out that all of the spray is collected and sieved, thus avoiding sampling errors; microscopic examination did not reveal any fracturing of the frozen droplets. This technique is restricted to liquids having melting point above − 20 °C, and to sprays with volume median drop diameter greater than 38 micron. In 114 runs, a wide range of nozzle sizes, spraying pressures, and liquid properties were covered; altogether seven liquid hydrocarbons were used, covering a range of viscosities of 10:1, densities 4:1, and surface tension 3:1.

The test results were correlated by dimensional analysis, the nondimensional quantities being formed of combinations of: air-core diameter, nozzle orifice diameter, mass-average velocity (axial, and tangential), orifice roughness factor, density, viscosity, and surface tension. A number of charts are shown, each representing a large number of test data, which cluster around median curves in close proximity, attesting the validity of assumptions. It is to be noted that the properties of the gas medium were not taken into account.

This is a carefully executed research project, representing a contribution of value to existing literature on sprays and nozzles.

AMR 14-5113

N-6. Neubauer, R. L., and B. Vonnegut

"Production of Monodisperse Liquid Particles by Electrical Atomization," Raymond L. Neubauer and Bernard Vonnegut (General Elec. Co., Schenectady, N.Y). J. Colloid Sci. 8, 551-2 (1953) cf. C.A. 47, 4167h.

CA 48-425c

N-7. Niepenberg, H.

Grundlagen der Düsen-Druckzerstäubung (Principles of pressure atomization with nozzles). Horst Niepenberg (Deutsche Babcock und Wilcox Dampfkesselwerke AG, Oberhausen/Rheinland, Germ.). Das Oelfeuer-Jahrbuch 1959. Verl. Gustav Kopf und Co., KG, Stuttgart, Germ. pp. 117–146, 24 fig., 4 tabl., 12 ref.

Treats: drop formation and drop-size distribution; influence of fuel fog quality on combustion; pressure-atomizing nozzles, their principles, calculation, and design; influence of viscosity on nozzle capacity and spray angle; jet breakup phenomena; energy required for atomization; approximate calculation of drop size; atomizers with secondary fluids; with steam; with low-pressure and with high-pressure air; droplet size as a function of velocity difference between the liquid and air; pertinent researches by NUKIYAMA and TANASAWA, LEWIS, EDWARDS, GOGLIA, RICE, and SMITH; impulse and energy of atomization; combustion air; influence of excess air on combustion; means for directing the air stream; function of conical burner shroud and impeller; air shroud with radial swirl guides. Treatment is mainly from practical aspects. Findings of recent (up to 1957) German, American, and British researches are included.

deJ II-295

N-8. Norgren, C. T.

N63-20216 National Aeronautics and Space Administration
Lewis Research Center, Cleveland, Ohio
ONBOARD COLLOIDAL PARTICLE GENERATOR FOR ELECTROSTATIC ENGINES
Carl T. Norgren Repr from Progr. Astron Aeron., v 9 N.Y. Academic Pr. Presented at the ARS Electric Propulsion Conf., Berkeley, Calif., Mar 14-16, 1962

A method of colloidal particle generation, based on the expansion and condensation of a material in a nozzle, has been investigated, and is shown to be capable of supplying particles suitable for acceleration in an electrostatic engine. The material is heated is heated in a small vaporizer which supplies a homogeneous vapor to a convergent-divergent two-dimensional nozzle, 15.5 cm long with a rectangular throat 0.273 by 4.48 cm. Flow rate and subsequent particle growth are controlled by regulating temperature and hence, vapor pressure of the material in the vaporizer. The experimental particle-size determination was obtained by visual inspection of photographs taken in an electron microscope. It is demonstrated that particle size can be controlled from 0.005 to 0.05μ and maintain narrow-range distributions suitable for engine application. The colloidal generator was incorporated into a small specialized electrostatic engine. A negative corona discharge was used to charge the colloidal particles and a Pierce accelerator was used to accelerate these particles. A calculated thrust density of 5.60×10^{-3} Newtons/m^2 at a specific impulse of 420 sec was obtained in engine operation.

N63-20216, 20-27

N-9. Northup, R. P.

Flow Stability in Small Orifices. R. P. Northup: Amer. Rocket Soc., ASME Ann. Meet., Atlantic City, 30 Nov. 1951.

Cited in PILCHER and MIESSE 1957. Investigated in injection nozzles for rockets the "hydraulic flip," i.e., the sudden change of the character of flow in the nozzle, when the jet fills the hole and when the jet separates from the hole walls. Investigated effect of "cross-velocity" on type of flow from the orifice. Term "cross-velocity" means the component of velocity, in the injector head, perpendicular to axis of holes through which the liquid issues. (These effects are discussed also in STEHLING 1952.)

deJ II-296

N-10. Novikov, I. I.

Laws of Atomization of Liquids by Centrifugal Nozzles (in Russian). I. I. Novikov. Jl. Techn. Phys. (USSR), Vol. 18 (1948), pp. 345–354, 3 fig. Abstract: Eng. Dig. (Engl.) Vol. 10, No. 3 (March 1949), pp. 72–74, 3 fig., 3 ref.

Mathematical analysis of atomization process of swirl chamber nozzles. Derives equation for equivalent diameter of drops (total volume divided by total surface) which decreases with increasing supply pressure and chamber diameter, but with decreasing diameter of the tangential supply. Compares the calculated equivalent diameters with those based on experiments of others, and finds good agreement, except for low pressures, where the influence of viscosity becomes appreciable. The equation is derived assuming that viscosity has negligible influence. Refers to work of Abramovich and Blinov.

deJ I-247

N-11. Nukiyama, S., and Y. Tanasawa

Experiments on the Atomization of Liquids in an Air Stream (in Japanese). Shiro Nukiyama and Yasushi Tanasawa. Trans. Soc. Mech. Engrs., Japan Vol. 4, No. 14 (Feb. 1938), pp. 86—93 and No. 15, pp. 138—143; Vol. 5, No. 18 (Feb. 1939), pp. 62—67 and 68—75; Vol. 6, No. 22 (1939), pp. II—7 and II—15 and No. 23 (1940), pp. II—18 to II—28 with 96 fig. Engl. translat. by E. Hope, Defence Research Board, Dep. Natl. Defence, Canada (1950).

Detailed study of air-atomization (as in oil burners, carburetors, fuel injection into injection into engines etc.); influence of relative velocity of liquid and air, air density, and physical property of liquid, particularly as regards drop-size distribution and spray dispersion. Description of method and equipment. Influence of air to liquid ratio; effect of sharp-edged and round-edged nozzle. Empirical equation for the size-range of droplets (which found wide acceptance in later spray studies). Experiments with water, gasoline alcohol and heavy oil. High-speed photographs of break-up of liquids into droplets, using three liquids of different surface tension, viscosity and specific gravity. Experiments with nozzles of various shapes set crosswise in the air jet; influence of location of nozzle tip. Several hundred spray photographs.

This investigation has been treated in detail in PIERCE 1947, and in LEWIS, EDWARDS, GOGLIA, RICE, and SMITH 1948.

deJ I-248

O-1. O'Brien, V.

532. O'Brien, Vivian, Why raindrops break up—vortex instability, *J. Meteorol.* 18, 4, 549–552, Aug. 1961.

The mechanism of breaking up of liquids into drops has engaged the attention of a long line of investigators for the past hundred years or so, because of its inherent fascination as a beautiful manifestation of subtle molecular forces, of its scientific interest as a means of determining important physical characteristics such as viscosity and surface tension, and of its industrial importance as a method of increasing the surface area through which exchange of energy and material can take place more effectively for chemical reactions, combustion, spray drying, evaporation, and other processes. The present work discusses the so-called "bag-breakup" of water drops, a hydrodynamic mode in which the initially spherical drop first flattens out to a flat ellipsoid then becomes a concave dish with a thick annular rim; the dish develops into a thin bag, the rim develops lumps; finally the bag bursts and the rim breaks up into a circlet of drops. Author points out the basic hydrodynamic similarity between a fluid pair composed of a liquid and gas (as in the case of raindrop), and a pair composed of two liquids. The phenomena of a finite body falling freely in another fluid are governed by gravity, shear, and normal pressure forces, and surface forces generated by the structure of the interface. Such a phenomenon takes place more slowly, hence it is better observable, in a liquid-liquid system, than it is in liquid in gas. A photo sequency of breakup shows: (1) oil drop in another, less dense oil in which it is miscible, (2) silicone-oil drop in mineral oil in which it is not miscible, and (3) ink drop in water, being miscible liquids of low viscosity. Author points out the common feature of these phenomena: vortex instability. There are 11 references to pertinent literature. This is an interesting paper, apparently a part of a longer investigation, to the publication of which one can look forward with anticipation of more details.

AMR 15-532

O-2. Oderfeld, J.

O Wielkosci Kropelek W Rozpylonym Paliwio (On droplet distribution in sprayed fuel). Jan Oderfeld (Warszawa, Poland). Archiwum Budowy Maszyn, Vol. 1, 1954, No. 3, pp. 363–369, 1 fig., 1 tabl., 14 equ., 4 ref. (with titl.).

Distribution of droplets mechanically sprayed in a gas turbine can be represented by the Rosin-Rammler function

$$F(x) = 1 - e^{-(x/x_m)^n}$$

where $F(x)$ is the fraction (by volume) of the fuel with droplet diameter less than x; x_m and n are the distribution parameters. Total surface area of the droplets in a spray, divided by the number of droplets, gives the surface area of the mean droplet, the corresponding diameter of which is the "mean droplet diameter"; the smaller this is, the more complete is the spraying. Describes experimental determination of drop-size distribution by the "hot-wax" method. Presents a nomogram by the aid of which the mean droplet diameter can be determined. Points out that a spray with equal-sized droplets is not necessarily the best for combustion.

deJ II-299

O-3. Oesterle, K. M.

Zum Einfluß des elektrostatischen Feldes auf Düsenaustrittsgeschwindigkeit und Zerfall von Lackstrahlen (Influence of the electrostatic field on the nozzle outflow velocity and breakup of varnish jets). K. M. Oesterle. Schweiz. Arch. angew. Wissenschaft und Techn., Vol. 23, 1957, No. 12, pp. 404–413.

Study of physical and chemical factors on electrostatic atomization of paints, for obtaining an uniform coating.

deJ II-299

O-4. Ohnesorge, W.

OHNESORGE 1936

Die Bildung von Tropfen ar Düsen und die Auflösung flüssiger Strahlen (Formation of drops by nozzles and the break-up of liquid jets). Wolfgang v. Ohnesorge (Foettinger-Institut, Berlin). Z. angew. Math. and Mech. (Germ.), Vol. 16 (1936), pp. 355–358, 4 fig. Abstract in VDI-Z. Vol. 81, No. 15 (Apr. 1937).

Shows by means of high-speed motion pictures that the breakup of a jet passes successively through three phases (breakup according to Rayleigh—breakup according to Weber-Haenlein—atomization), and that the transition from one phase to the next occurs at increasingly higher Reynolds No's. as a function of a dimensionless term, containing viscosity, surface tension, density, and orifice diameter: $Z = \eta/\sqrt{\sigma\rho d}$ where η is the absolute viscosity, σ is the surface tension, ρ is the density and d is the orifice diameter.

deJ I-253

O-5. O'Konski, C. T. and H. C. Thacher

4664* The Distortion of Aerosol Droplets by an Electric Field. Chester T. O'Konski and Henry C. Thacher, Jr. *Journal of Physical Chemistry*, v. 57, Dec. 1953, p. 955-958. Presents theoretical analysis. Tables. 11 ref.

BMI 3-4664

O-6. Olson, E.

"Atomization of Liquid Fuels" ASHRAE Journal 1, 68-9 (Aug 1959)

O-7. Osamu, G.

"Atomization of Liquid by High Voltage." I. Gohei Osamu - (Electrostatic Painting Machine Co. Ltd., Osaka). J. Electrochem Soc. Japan 24, 229-33 (1956).

CA 51-2305c

O-8. Oyama, Y.; M. Eguchi, and K. Endou

"The Trajectory of Water Droplets in Centrifugal-Disk Atomization." Yoshitoshi Oyama, Masayuki Eguchi, and Kazuo Endou (Tokyo Inst. Technol.). Chem. Eng. (Japan) 17, 296-301 (1953); cf. C. A. 47, 7834h.

CA 47-9064b

0-9. Oyama, Y. and K. Endou

"Centrifugal Disk Atomization. Theoretical Considera-
tion." Y. Oyama and K. Endou (Tokyo Inst. Technol.).
Chem. Eng. Japan 17, 256-60 (1953).

CA 47-78341

P-1. Palmer, F., and S. S. Kinsbury

"Particle Size in Nebulized Aerosols," Frederic Palmer and Stuart S. Kinsbury (Franklin Institute). Am. J. Pharm. 124, 112-24 (1952).

CA 46-9251b

P-2. Palmer, R. S.

"Water Jet Breakup from Stainless Steel Tubes," Agricul. Engr. 43, 456-7 (Aug. 1962).

P-3. Panasenkov, N. S.

769. Panasenkov, N. S., Effect of the turbulence of a liquid jet on its atomization (in Russian), *Zh. tekh. Fiz.* 21, 2, 160-166, Feb. 1951.

Photographic measurements were made of the length before atomization of a water jet discharging into the atmosphere, as a function of Reynolds number based on orifice diameter. The length increased up to $R = 4200$ and then dropped off sharply, presumably because of the establishment of turbulent flow. Average drop size after atomization of a turbulent jet was found to be almost independent of Reynolds number, but approximately proportional to orifice diameter. The data were fitted by the empirical curve $D_{drop} = 6D_{orifice}/R_e^{0.16}$.

AMR 5-769

P-4. Panevin, I. G.

O raspilivanii zhidkosti forsunkoy co stalkivayush-chimisja strujami (Atomization of liquids in colliding jets). I. G. Panevin (Moskovskij Aviacionnij Institut, Moskva, USSR). Trudi MAI. vip. 119. Obrongiz, Moskva, USSR, 1960, pp. 85-101, 7 fig., 11 ref.

Reviews previous researches of Lee, Fry and Thomas, Heidmann and Humphrey, Hagerty and Shea, Oka, Squire. Investigates the stability of liquid sheets; derives correlation for optimal wavelength of vibration at which the breakup of the film is the most intensive. Experiments were made with water, taking micro-flash photos, in the following ranges: nozzle orifice 1 to 2 mm. diam., angle of collision 40 to 160 deg., nozzle pressure 1 to 15 atm. Median diameter of droplets decreased linearly with increase of velocity; droplet diameter increased linearly with the increase of orifice; droplet diameter decreased with increasing angle of collision.

deJ II-305

P-5. Panevin, I. G.

O raspredelenii zhidkosti v fakelo forsunki so stalkkivayush-chimisja strujami (Distribution of liquid in impinging jets). I. G. Panevin (Moskovskij Aviacionnij Institut, Moskva, USSR). Trudi MAI vip. 119. Oborongiz, Moskva, 1960, pp. 72-84, 5 fig., 4 ref.

Reviews previous work of Wittenbauer, Lee, Bond, Kretschmar, and Wedaa. Derives a method for determining the distribution of liquid in two jets in collision. Describes experimental apparatus, and experimental results with water and with kerosine, which show fair agreement with the computed values.

deJ II-305

P-6. Park, R. W., and E. J. Crosby

3070 A Device for Producing Controlled Collisions Between Pairs of Drops.—Collisions were promoted between uniformly sized, equally spaced drops from two converging streams in a repeated fashion at frequencies ranging up to several thousand events per sec. – R. W. Park and E. J. Crosby. *Chemical Engineering Science*, v. 20, no. 1, Jan. 1965, p. 39-45.

BMI 14-3070

P-7. Partington, J. R.

"An Advanced Treatise on Physical Chemistry, Vol. II. The Properties of Liquids," Longmans, Green & Co., New York, 1951.

P-8. Pattison, J. R., and J. D. Aldridge

3671. Pattison, J. R., and Aldridge, J. D., Atomisation of water by spinning discs, *Engineer, Lond.* 203, 5280, 514-519, Apr. 1957.

Characteristics of water sprays produced by spinning disks of various designs, and mechanism of droplet formation have been studied. Grooved disks with flat annuli prevent surface slip but do not reproduce the atomization processes occurring on plane disks. Vaned disks prevent slip but give fairly homogeneous sprays by the break up of small filaments at the disk edge in same way as plane disks. A simple formula relating drop diameter to liquid and disk parameters is discussed and shown to represent an over-simplification of the drop-formation process. A qualitative explanation is given for the drop spectra obtained. Several methods of dropsize measurement were investigated; finally, the method of capturing the drops on a microscope slide covered with a layer of magnesium oxide was adopted. The spectra of drop-size distribution is given in two representations: number of drops versus drop diameter, and volume of liquid versus drop diameter. Both the grooved disk and the vaned disk are illustrated.

AMR 10-3671

P-9. Paul, H. I., and C. A. Sleicher

"The Maximum Stable Drop Size in Turbulent Flow: Effect of Pipe Diameter," Chem. Eng. Sci. 20, No. 1, 57-59 (Jan 1965).

P-10. Payne, R. B.

858. Payne, R. B., A numerical method for calculating the starting and perturbation of a two-dimensional jet at low Reynolds number, *Aero. Res. Counc. Lond. Rep. Mem.* 3047, 39 pp. + 20 graphs + 11 figs., 1958.

The jet emerges from a slit in a plane wall. Source strength increases linearly from zero to certain value, then remains constant. Motion is computed for equal time steps on Manchester I computer. Vorticity is carried along by the velocity, and the subsequent velocity is computed by integrating the effect of the new vorticity field. Motion begins as potential flow and, to satisfy condition of no slip at the boundary, vorticity is introduced there. This vorticity is conducted into the body of the fluid by viscosity. Distribution of vorticity and velocity are shown in diagrams for several low Reynolds numbers. Front of jet has two whirls of opposite rotation whose vorticity is gradually conducted into the surroundings.

Several sources of error are thoroughly investigated; these are mainly results of computing techniques, not of physical aspects of the method. Method is a powerful one, but suitable only for automatic high-speed machines.

AMR 12-858

P-11. Perron, R. R., J. R. Swanton, and E. S. Shanley

"A Practical Ultrasonic Burner," Proceedings API Research Conference on Distillate Fuel Combustion, Conference Paper No. CP 63-1. June 18-19, 1963.

P-12. Peskin, R. L., and R. J. Raco

1871. Peskin, R. L., and Raco, R. J., Drop size from a liquid jet in a longitudinal electric field, *AIAA J.* 2, 4, 781-782 (Tech. Notes and Comments), Apr. 1964.

A relationship between the drop sizes found by the breakage of an unstable liquid jet with and without the presence of a longitudinal electric field is developed. Experimental results are in satisfactory agreement with the relation derived.

AMR 18-1871

P-13. Peskin, R. L., and R. J. Raco

1874. Peskin, R. L., and Raco, R. J., Ultrasonic atomization of liquids, *J. Acoust. Soc. Amer.* 35, 9, 1378-1381, Sept. 1963.

A theory of ultrasonic atomization of liquid films is presented. It is assumed that exponential growth of surface disturbances ultimately results in the formation of liquid drops, the diameters of which are proportional to the wavelength of the most rapidly growing initial disturbance. The hydrodynamic stability equations of the liquid film are examined, and the most rapidly growing initial disturbances are determined by numerical solution in the unstable region. *A resultant correlation between drop size, transducer frequency, transducer amplitude, and liquid-film thickness is obtained. Results are compared to previous theoretical and experimental conclusions.*

AMR 18-1874

P-14. Peskin, R. L., and R. J. Raco

"Some Results from the Study of Ultrasonic and Electrostatic Atomization," 1963 API Research Conference on Distillate Fuel Combustion Paper CP63-3.

P-15. Peskin, R. L., and J. P. Lawler

"Results from Analytical Studies of Droplet Formation," Proceedings API Research Conference on Distillate Fuel Combustion, Conference Paper No. 62-2, June 19-20, 1962

P-16. Pfaff-Grossmann, S.

Bemerkungen zum Einfluß der Oberflächenspannung der Zerstäuberflüssigkeit auf die Teilchengrößenverteilung bei Ringspaltdüsen (On the influence of surface tension of the atomized liquid on the size-distribution of drops in annular nozzles). S. Pfaff-Grossmann (Univ. Mainz, Germ.), Schwebstofftechn. Arbeitstagung 1955, Univ. Mainz, Germ., pp. 86–87, 1 fig.

Aerosols were produced using an annular-slit atomizer nozzle developed at Univ. of Mainz. Drop-size was obtained by measuring the falling velocity and applying the Stokes-Cunningham Law. Surface tension of a salt solution was varied by the admixture of a jellying substance which left the density and viscosity unchanged. Surface tension was determined by both a static and a dynamic method; both yielding approximately the same result.

deJ I-263

P-17. Pfaff-Grossman, S.

Die Größenverteilung von Aerosolen in Abhängigkeit von den Dimensionen der Zerstäubungsdüse und den physikalischen Eigenschaften der zerstäubten Flüssigkeit (Size distribution of aerosols as a function of the dimensions of the atomizing nozzle and of the physical characteristics of the atomized liquid). S. Pfaff-Grossmann (Univ. Mainz, Germ.). Schwebstofftechn. Arbeitstagung 1954, Univ. Mainz (Germ.), pp. 12–16, 3 fig.

The nozzle used was of the annular slit type, the width of which could be adjusted at will. In operation the slit was submerged a certain depth below the liquid surface. A pressure gas issues from the slit and disperses the liquid. The size of the issuing droplets was estimated by observing, in an ultramicroscope, the sinking velocity of the droplets, from which, by means of the Stokes-Cunningham law, the droplet size could be calculated. With increasing gas pressure the mean drop size was found to decrease. The most favorable slit width was found to be 100 microns. The droplet mean diameter became larger as the surface tension of the liquid was increased and as the viscosity of the liquid was increased.

deJ I-263

P-18. Pfeiffer, A.

"Rebound of Liquid Drops from a Solid Surface," U.S. Army Chem. Res. and Devel. Labs., Tech. Report CRDLR 3220, July, 1964.

P-19. Piazza, J., and J. C. Fittipaldi

"Centrifugation of Films Adhering to a Divergent Rotor, in Contact with a Liquid Surface." José Piazza and Julio C. Fittipaldi. Rev. fac. ing. quím. 21-22, 29-42 (1952-53) (Pub..1953); cf. ibid. 20, 27 (1951).

CA 49-7295g

P-20. Pickroth, G., and F. Spitzenberg

9017. **Ultrasonic nebulization, a new method for the production of aerosols.** G. PICKROTH AND F. SPITZENBERG. Note in *Naturwissenschaften*, **41**, *No.* 9, 209 (1954) *In German.*

This is a brief advance statement on the possibility of using ultrasonic methods for producing dense aerosols (1 cm³ of fluid in 6 l of air) for medical treatments requiring inhalation. The size of the droplets shows a small spread about a maximum of 2·5 μ; control is easy and an exact dose can be given.

PA 57-9017

P-21. Pierce, E. T.

8079. EFFECTS OF HIGH ELECTRIC FIELDS ON DIELECTRIC LIQUIDS. E.T.Pierce
J. appl. Phys., Vol. 30, No. 3, 445-6 (March, 1959).

The drop size and repetition frequency in spray from a negatively charged nozzle, towards a positive ring electrode, are determined by the relaxation time (permittivity/conductivity) of the liquid and by the amplitude of the stress applied. Electrophoretic effects are believed to occur in liquids containing ionic impurities, whereas dielectrophoretic effects are dominant in highly pure liquids

PA 62-8079

P-22. Pierce, N. C.

Efficiency of Hydraulic Nozzles for Atomization. N. C. Pierce. M. S. Thesis, Univ. of Illinois, (1947), 46 p., 22 fig., 14 ref.

Reviews the empirical formulas of Nukiyama and Tanasawa (NUKIYAMA and TANASAWA 1940), of Longwell, and the work of Lewis, Edwards, et al. Reports experiments on 3 different nozzles, mainly on swirl chamber nozzles (75 and 140 psi, 0.031–0.060 in. orifice dia using water). Exposes magnesium oxide covered slide to spray for a definite time by means of a clock-spring operated shutter; counts drops as small as 0.020 mm. diameter. Plots results according to method of Nukiyama and Tanasawa; Shows some spray photographs. Finds that drop size decreases with decreasing orifice diameter, swirl chamber depth, swirl chamber entrance size.

deJ I-264

P-23. Pigford, R. L.

"Automatic Determination of Size Distributions of Heterogeneous Liquid Sprays," presented U.S. Tech. Conf. on Air Poll., Washington, D.C., May 2, 1950.

P-24. Pigford, R. L., and C. Pyle.

"Performance Characteristics of Spray-Type Absorption Equipment," Ind. Eng. Chem. 43, 1649 (July 1951).

P-25. Pilcher, J. M.

Characteristics of Sprays and Droplets. J. Mason Pilcher (Battelle Memorial Institute, Columbus, Ohio). Paper presented at Confer. an Atomization, Sept. 1953. The Techn. Inst., Northwestern Univ., Evanston, Illinois. Project SQUID Tech. Rep. No. NTI-1 C, AD-50-186, pp. 1–14, 5 fig., 11 ref.

Effect of atomization on size and surface area of drops; measurement of drop-size distribution with the cascade impactor; construction, calibration and limitations of Battelle cascade impactor; dynamics of droplets; terminal velocity of water drops in air; drag coefficients of drops; distortion of drops; initial velocity of drops issuing from centrifugal spray nozzles; dynamic effect of drops upon each other.

deJ I-265

P-26. Pilcher, J. M., and C. C. Miesse

The Mechanism of Atomization. J. M. Pilcher and C. C. Miesse (Battelle Memorial Inst., Columbus, Ohio). Chapter 1 in BATELLE MEM. INST. 1957, "Injection and Combustion of Liquid Fuels," March 1957, 57 p., 23 fig., 96 equ., 1 tabl., 52 ref. (with titl.).

Reviews theories on the mechanism of liquid disintegration into droplets (RAYLEIGH 1879, 1892; WEBER 1931; CASTLEMAN 1931, 1932, and others). Atomization takes place in three steps: (a) initial disturbance of the surface of liquid jet, (b) formation of ligaments which then break up into fragments, (c) further breakup of fragments into smaller droplets. Problem of determining theoretically the form of disturbance that leads most rapidly to jet instability has been solved for some typical cases, based on reasonable physical assumptions; but the ultimate problem of determining the drop-size distribution that finally results is far from solution. Most important factors influencing drop size are: (a) nozzle design, (b) operating conditions, especially pressure, and (c) properties of liquid and of air into which it is injected. Major factor is the relative velocity between the liquid and the air.

See Putnam et al. deJ II-309

P-27. Pilcher, J. M., and C. C. Miesse

Methods of Atomization. J. M. Pilcher and C. C. Miesse (Battelle Memorial Inst., Columbus, Ohio). Chapter 2 in BATTELLE MEM. INST. 1957, "Injection and Combustion of Liquid Fuels," March 1957, 24 p., 17 fig., 25 equ., 29 ref. (with titl.).

Discusses five basically different methods: (1) solid injection, using pressure nozzles, (2) two-fluid atomization, whereby the liquid is disintegrated by encountering high-velocity steam or gas, (3) rotating disc or cup, from the periphery of which the liquid is thrown at high velocity, (4) vibrating devices employing sonic or mechanical vibration, (5) impinging jets, in which the liquid is atomized by collision of two liquid jets. Reviews work of Joyce, McEntee, Fogler and Kleinschmidt, Hougton, Limper, Cadle and Magill, Walton and Prewett, Adler and Marshall, Hinze and Milborn (ligament formation by rotating cup), giving detailed abstracts and showing figures.

See Putnam et al. deJ II-310

P-28. Pilcher, J. M., and C. C. Miesse

Design of Atomizers. J. M. Pilcher and C. C. Miesse (Battelle Memorial Inst., Columbus, Ohio). Chapter 3 in BATTELLE MEM. INST. 1957, "Injection and Combustion of Liquid Fuels," March 1957, 39 p., 23 fig., 2 tabl., 36 ref.

Discusses fundamental principles, various types of vortex or swirl-type nozzles, which are almost universally used on aircraft gas-turbine engines, two-fluid nozzles, and reactant injectors for rockets, especially the impinging-jet type. Lists requirements of a good nozzle, surveys hydrodynamic theories of flow phenomena in nozzle and in spray based on TAYLOR

1948 and 1950, and other previous researches on spray angle (SOEHNGEN and GRIGULL 1951; NOVIKOV 1948; HARVEY and HERMANDORFER 1941) and on other spray properties. Analyses a number of actual injector nozzle designs. Lists some empirical formulas for spray angle and fineness of atomization.

See Putnam et al. deJ II-310

P-29. Pilcher, J. M., C. C. Miesse, and A. A. Putnam

Spray Analysis. J. Mason Pilcher, C. C. Miesse, and A. A. Putnam (Battelle Mem. Inst., Columbus, Ohio). Ch. 4 in BATTELLE 1957, 109 p., 59 fig., 3 tabl., 120 ref.

Discusses experimental methods for determining drop-size distributions, including: (1) microscopic examination of drops collected on slides or in cells, (2) freezing of drops in spray followed by sieving, (3) direct photographing methods, (4) optical methods based on scattering or absorption of light, (5) electronic and radioautographic techniques, (6) selective impaction. Shows sketches of arrangements, and devices, appraises error sources, advantages and disadvantages, and fields of application of each method. Discusses mathematical representations of drop-size distributions, particularly the „Rosin-Rammler", the „Nukiyama-Tanasawa", and „logarithmico-normal" expressions. Stresses importance of taking into account both the upper and the lower cut-off sizes. Discusses also cone angle of spray, distribution of droplets about the axis ("patternation"), and their influencing factors. Shows different measuring instruments; explains their operating principles.

See Putnam et al. deJ II-310

P-30. Pilcher, M., and R. E. Thomas

1791. Pilcher, M., and Thomas, R. E., Drop-size distribution of fuel sprays, Amer. Chem Soc., Advances in Chem. Series no. 20, 155-165, 5 figs., 77 ref., 1958.

Basic requirement for a systematic research on liquid fuel combustion is the accurate determination of drop-size distribution in the fuel spray.

Experimental methods for determining the drop-size distribution of fuel sprays are reviewed. The procedures described are of six general types: microscopic examination of drops collected on slides or in cells; freezing of drops in spray followed by sieving; direct photographic methods; optical methods based on the scattering or absorption of light; electronic and radioautographic techniques; and selective impaction. Advantages and disadvantages of each method are pointed out and special attention is given to the importance of representative sampling of the spray. Mathematical expressions for basic drop-size distributions are included. Averages and moments of the length-, surface-, and volume-weighted forms of these distributions are summarized. Principal relations existing among the corresponding arithmetic, geometric, and harmonic means are tabulated. Formulas for (1) normal-size, (2) log-normal-size, (3) Rosin-Rammler, and (4) Nukiyama-Tanasawa distributions are given.

AMR 11-4791

P-31. Pischinger, A., and F. Pischinger

13922* New Research Data on Liquid Fuel Jets. Neue Untersuchungsergebnisse an Brennstoffstrahlen. (German.) A. Pischinger and F. Pischinger. *Osterreichisches Ingenieur-Archiv*, v. 9, nos. 2-3, 1955, p. 207-215.

Optical precision measurements on fuel jets have provided new information on their behavior in stagnant and moving air, and have shown the influence of the nozzle shape. Injections made into a vacuum have made possible conclusions concerning flow in the nozzle.

BMI 4-13922

P-32. Plateau, J.

Statique Experimentale et Theorique des Liquides Soumis aux Seules Forces Moleculaires (Experimental and theoretical statics of liquids subjected solely to molecular forces). 1873.

Treats liquid films, bubbles, compact liquid spheres and cylinders. Finds that a liquid cylinder formed between two solid ends is in unstable equilibrium if the proportion of its length to its diameter exceeds a certain value, which is between 3 and 3.6. Beyond this value the liquid cylinder is spontaneously converted into a series of discrete spheres of equal diameters, equal distance apart. (Cited in RAYLEIGH 1892.)

deJ I-127

P-33. Plateau, J. A. F.

Recherches Experimentales et Theoriques sur les Figures d'Equilibre d'une Masse Liquide sans pesanteur (Experimental and theoretical researches on the figures of equilibrium of a liquid mass without weight). J. Plateau. Ann. de Chimie et de Phys., 4th Ser., Vol. 17, 1869, pp. 260-276, 2 tabl.; Vol. 19, 1870, pp. 369-389. (Gives list of preceeding publications on subject.)

Abstract by author of his original, extensive publications: PLATEAU 1849-1868. Treats: causes influencing the persistence of liquid sheets; surface tension of liquids; new principle of these surfaces; work of previous investigators: Hagen, Dupré, Leidenfrost, Segner, Young, Van der Mensbrugghe, Quincke; accessory causes which influence the persistence of liquid sheets; laminar figures of very long duration; history regarding liquid films; capillary ascension of large heights in tubes of large diameters; constitution of a gas current which traverses a liquid.

deJ II-312

P-34. Plateau, J. A. F.

Memoire sur les phenomènes que présente une masse liquide et soustraite a l'action de la pesanteur. I° Serie. Joseph Antoine Ferdinand Plateau (Professor, Univ. Ghent, Belgium; b. 1801, d. 1883). Memoires de l'Academie Belge, Tome XVI, 1843. Recherches experimentales et theoriques sur les figures d'equilibre d'une masse liquide sans pesanteur. II° Serie. Memoires de l'Academie Belge, Tome XXIII, 1849. Idem III° Serie, 1856, Tome XXX; Idem IV° Serie, 1858, Tome XXXI; Idem V° et VI° Serie, 1861, Tome XXXIII; Idem VII° Serie, 1866, Tome XXXVII; Idem VIII° Serie, 1868, Tome XXXVII; Idem IX° Serie, 1868; Idem X° Serie, 1868; Idem XI° Serie, 1868.

These papers have been published in English translation, up to and incl. the VIth Series, in the Annual Reports of the Smithsonian Institution, as follows: First Series in Ann. Rep. 1863, pp. 203-285, 30 fig.; Second Series in Ann. Rep. 1864, pp. 285-307; Third Series pp. 308-337; Fourth Series pp. 338-369, 40 fig.; Fifth Series in Ann. Rep. 1865, pp. 411-435, 9 fig.; Sixth Series in Ann. Rep. 1866, pp. 255-289, 33 fig. Title is: The Figures of Equilibrium of a Liquid Mass Withdrawn from the Action of Gravity. With an Introduction by Joseph Henry, Secretary of the Smithsonian Institution, in Ann. Rep. Vol. 1863, pp. 207-208. Following abstract is based on the translation of the Smithsonian Institution.

First series deals with the behavior and characteristics of a sphere of oil suspended in a mixture of alcohol and water having a density equal to that of the oil. Describes in painstaking detail the method of producing an oil sphere of about 2 in. diam., rotating it slowly whereby it assumes an ellipsoid form and then flattens still more and finally forms a separate ring. Ser. II discusses: pressure produced by surface tension at a given curvature of the surface; a solid system placed inside the oil sphere; method of forming a lenticular body of oil inside a metal ring whereby light-refraction phenomena can be produced; many other forms of oil bodies shaped by wire frames. Explains properties of figures of equilibrium bounded by plane surfaces, liquid polyhedra, laminar figures of equilibrium, figures of revolution, particularly cylinders; calculates main dimensions. Determines limits of stability of a cylindrical body of oil; illustrates and explains the successive steps in the breakup of a long liquid cylinder into spherical droplets; calculates time of breakup. Discusses flow of liquid from the orifice in the horizontal bottom of a receptacle; derives flow equations; refers to investigations of Savart to explain the vibration of jet by its alternate dilatation and constriction. Ser. III discusses theory of liquid jets issuing from a circular orifice, their modifications under influence of vibratory movements, and resulting dilatations and constrictions. Mentions experiments by sounding a musical instrument near the liquid jet, thereby inducing vibrations in the latter; discusses effect of multiples and submultiples of the sound frequency to jet-vibration frequency. Ser. IV deals with mathematical theory of figures of equilibrium of revolution, particularly their radius of curvature; treats in detail the "unduloid" figure which represents the various shapes through which an initially cylindrical jet passes into the state of discrete spherical drops; finds that the unduloid is identical with the catenary curve, having the property that at each point of the meridian line the radius of curvature is equal and opposite to that of the perpendicular section. Lists figures of equilibrium of revolution of a liquid mass withdrawn from the action of gravity: (1) sphere, (2) plane, (3) cylinder, (4) unduloid, (5) catenoid, (6) nodoid. All these, except the sphere, have infinite dimension in the axial direction; therefore only the sphere can be realized with a finite mass of liquid. Ser. V deals with figures of equilibrium of oil films which do not contain oil inside them; describes the painstaking technique necessary for their experimental production and investigation. Determines the pressure exerted by a spherical film on the air contained; investigates the limiting radius of sensible molecular attraction for a glyceric liquid; gives instructions for preparation of glyceric liquid. Ser. VI discusses theory of liquid films, constitution of froth, generation of films, production of films by framework of a variety of geometric shapes, geometric construction of contacting bubbles forming the froth. Lists early researches in the field of surface tension, liquid jets, and their breakup: HOUGH 1830, SAVART 1833, DELAUNAY 1841, DONNY 1843, HENRY 1844, HAGEN 1846 and 1849, MATTEUCCI 1846, BILLET-SELIS 1851, DeJEAN 1855, MAGNUS 1855, BEER 1857. These are listed separately in present compilation. For detailed mathematical treatment of the "Problem of Plateau," i.e., the minimal surface connecting a given boundary line. see RADÓ 1933.

deJ II-311

P-35. Plateau, J. A. F.

Über die Grenze der Stabilität eines flüssigen Zylinders (On the stability limit of a liquid cylinder) J. Plateau. Poggendorff's Ann. d. Physik u. Chemie, Vol. 80, 1850, pp. 566–569. (Abstract from French: Sur la Limite de la Stabilité d'un Cylindre Liquide.)

Refers to his own investigations (2-nd Ser.) in which he found experimentally that the limit of stability of a liquid cylinder lies between 3.0 and 3.6-times the radius. Finds this is at variance with the value in HAGEN 1850, giving the value as 2.828. Derives a theoretical value of π, i.e., 3.141.

deJ II-312

P-36. Plit, I. G.

AD-413 583 Div. 25
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Foreign Tech. Div., Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.
INVESTIGATION OF DISPERSE ATOMIZATION IN NOZZLES OPERATING ON THE PRINCIPLE OF THE BILATERAL WASHING OF A LIQUID SURFACE WITH GAS, by I. G. Plit. 15 May 63, 20p.
FTD TT63 290 Unclassified report

Trans. from Zhurnal Prikladnoy Khimii, 35:9, pp. 1996–2007, 1962.

Descriptors: (*Atomization, Nozzles), (*Sprays, Atomization), (*Nozzles, Atomization), Drops, Liquids, Surfaces, Gases.

When investigating the influence of the basic parameters on the dispersity of a spray of liquids in low-pressure pneumatic nozzles, it was established that there are two characteristic regions, depending on atomization conditions, in which the mean drop diameter changes according to various regularities. Generalized equations were obtained for each indicated region for determining the critical point of transition from one dependence to the other.

TAB U63-4-4

P-37. Plockinger, F.,

2190. Plockinger, F., Characteristic numbers of atomization (in German), *Maschinenb. u. Waermewirtsch.* 11, 8, 217–220, 1956.

An attempt is made to find common theoretical basis for the characterization of atomizing nozzles. Author distinguishes two main types: I. Atomizers using purely a pressure in which the liquid is forced at high speed into quiescent air; II. atomizers using pressure air, in which the liquid itself is at rest while the atomizing air has high speed. Then the forces entering into the atomizing process are considered: friction, viscosity force, inertia force such as impact with a plate or impact of two jets, or centrifugal force. Finally, author distinguishes three basic kinds of drop formation: (a) drop emerging from a tube end, (b) disruption due to outside forces, (c) disintegration by wave formation. The characteristic numbers are derived on the basis of assuming one or the other kinds of forces having predominant influence, and using the methods of dimensional analysis. In general, nine kinds of dimensionless numbers are possible, but only a few have importance, in particular the Reynolds number, the Froude number, and the Weber number.

AMR 11-2190

P-38. Pobiarzhin, P. I.

3902. Pobiarzhin, P. I., An investigation of the influence of internal vorticity on atomizing quality and the jet of atomized fuel (in Russian), Dvigateli Vnutr. Sgoraniya (MVTU, 76), Moscow, Mashgiz, 1958, 84–103; *Ref. Zh. Mekh.* no. 4, 1959, Rev. 3718.

An experimental investigation of the influence of vorticity in the fuel stream of an open-type burner nozzle on the quality of atomization and the enclosed angle of the atomized fuel jet, the vortices being created by consecutive chokes arranged before the exit opening. The tests were made with a model of an open burner nozzle, in which differing degrees of vorticity of the full stream could be created by throttling the fuel in nozzles with a single, centrally-arranged aperture of varying size, the distance between the nozzles being adjusted by setting a movable plate between them. In the experiments the rate of fuel flow and pressures in front of the entry and exit nozzles, mean diameter of the fuel droplet apex angle of the fuel jet and the flow coefficients of the entry and exit nozzles were determined. The experiments were made under continuous fuel feed. The fuel was injected into air at atmospheric pressure. Droplet sizes were measured by catching them on a smoked plate, set in a special drop-catcher. The prints of the droplets on the smoked plate were measured under the microscope with 280 diameters magnification. The tests were made with diesel fuel of a specific gravity of 0.853. The apex angle of the fuel jet was determined photographically. From hydraulic analysis of variant burner forms the author derives relationships between the pressures in front of the entry and exit nozzles, and the rate of flow of the fuel, also between the flow coefficients of these nozzles and the pressure gradient in the nozzle, as well as the pressure in front of the nozzle. The measurements of droplet size showed that the mean droplet diameter is smaller for the burner with two nozzles than with only one. Consequently, the presence of a second throttling nozzle or choke in the burner materially influences the droplet dimensions. The apex angle of the fuel cone for the burner with two nozzles is considerably greater than for that with only one nozzle, although in the first case the pressure in front of the exit nozzle is lower. The specific fuel consumption of the tested burner variants has been calculated, and the specific energy balances set up. It is found that the open-type burner with two throttling sections gives finer atomization and a wider cone angle of the fuel jet than an open-type burner with only one nozzle. These differences can be explained by swirling of the fuel stream in the space between the nozzles.

AMR 14-3902

P-39. Pohl, H. A.

16240 FORMATION OF LIQUID JETS IN NONUNIFORM ELECTRIC FIELDS. H.A.Pohl.
J. appl. Phys. (USA), Vol. 32, No. 9, 1784-5 (Sept., 1961).
A note on the paper by Horgan and Edwards (preceding abstract) suggesting that the fountain effect is a combination of dielectrophoresis and electrophoresis.

PA 64-16240

P-40. Polyakov, E. I.

4316. Polyakov, E. I., **Experimental investigation of axially symmetric turbulent jets,** *Soviet Phys.-Tech. Phys.* 5, 10, 1173-1179, Apr. 1961. (Translation of *Zh. Tekh. Fiz., Akad. Nauk SSSR* 30, 10, 1238-1244, Oct. 1960 by Amer. Inst. Phys., Inc., New York, N. Y.)

Paper presents the results of an experimental study of the principal axially symmetric forms of incompressible free turbulent jets. Simple equations are supplied for analyzing the principal parts of jets and are found to be in satisfactory agreement with experiment.

AMR 14-4316

P-41. Ponstein, J.

6756 INSTABILITY OF ROTATING CYLINDRICAL JETS. J.Ponstein.
Appl. sci. Res. A, Vol. 8, No. 6, 425-56 (1959).
A mathematical treatment is given of the instability of rotating cylindrical jets under the action of the inertial effects of the jet and its surface tension. Three types of jet are considered: (a) the one whose liquid fills the space within a cylinder (solid jet); (b) the one whose liquid fills the space between two cylinders (hollow jet); (c) the one whose liquid fills the space on the outside of a cylinder (hollow, infinitely thick jet). In general the viscosity of the liquid and the inertial effects of the surrounding air have been neglected except in two cases: (1) For the non-rotating solid jet, the influence of the liquid viscosity is taken into account, while the inertial effects of the surrounding air are neglected, especially for rotationally symmetric perturbations. (2) For the rotating solid jet, the influence of the inertial effects of the surrounding air is taken into account, while the liquid viscosity is neglected. Here the undisturbed velocity field for the air is put equal to zero or is chosen in such a way that the overall velocity field is continuous at the interface between liquid and air. The following conclusions may be drawn: (A) If the liquid viscosity and the inertial effects of the ambient air are neglected: (1) The instability of the jets becomes greater if the ratio between their dynamic surface tension and the liquid density becomes greater. (2) In some cases non-rotationally symmetric perturbations are more unstable than rotationally symmetric ones. (3) The non-rotating jet is stable to perturbations whose wave number in a tangential direction is a positive integer. (4) The perturbations of the solid and hollow, infinitely thick jets are unstable if the wave number in axial direction lies in a finite interval between zero and a certain critical value, or if the wave number in a tangential direction takes the value zero or any integral value below a critical integer (only positive wave numbers are considered). (5) The solid jet is more unstable as it rotates faster; then the critical wave numbers in both axial and tangential directions are raised. (6) The hollow, infinitely thick jet is the more stable as it rotates faster; then the critical wave numbers in both axial and the tangential direction are lowered. (B) If the inertial effects of the ambient air or the liquid viscosity are taken into account: (7) The influence of the inertial effect of the ambient air on the solid jet may be neglected if the density of the air is small compared with the density of the liquid and if the velocity field is continuous at the interface. (8) The instability range of the wave number in an axial direction for solid (non-rotating) jets with low liquid viscosity is the same as that for solid jets with zero liquid viscosity for rotationally symmetric perturbations. The amplitude of the perturbations, however, grows somewhat more slowly with time than in the case of zero viscosity.

PA 63-6756

P-42. Popov, V. F.

"Evaluation of the Quality of the Dispersion Spray Obtained by the Ultrasonic Dispersion of Liquids and Melts." V. F. Popov. Khim. Prom. 1964 (12), 898-901 (Russ).

CA 62-10096c

P-43. Popov, M.

Popov, Mintscho.
MODEL EXPERIMENTS ON ATOMIZATION OF LIQUIDS (Modellversuche mit Flussigkeitszerstäubung) tr. by S. Reiss. July 61, 33p. 9 refs. NASA Technical trans. F-65; AD-260 000.
Order from OTS $1.00 61-31567

Trans. of Rev[ue] de Mécanique Appliquée (Rumania) 1956, v. 1, no. 1, p. 71-88.

DESCRIPTORS: *Atomization, Drops, Hydraulic systems, Liquids, Fluids, *Fluid mechanics, Photographic analysis, Water impingement, Jets, Fuel sprays.

The similarity laws are determined for the atomization of liquids with constant material properties and to verify them by comparison model experiments. The analyses show that the effect of the viscosity of the gas was very small and that approximate model experiments can be carried out without considering the ratio M of the gas to liquid viscosity, a condition that is difficult to satisfy. The derived and experimentally verified similarity laws permit the modeling of the atomization processes of liquids whereby considerable simplifications in experimental procedure and generalization of the experimental data are made possible.

T7-35

P-44. Popov, M.

1151. Popov, M., Investigation of an injection nozzle having a variable spray cone angle, *Annuaire de l' Ecole Polytechnique d'Etat.* 1953, Sofia, Bulgaria, 1-28.

The purpose of this investigation was to develop an injection nozzle for internal combustion engines which would produce a spray, the cone angle of which would vary during the injection, in order to obtain a thorough mixing of the liquid droplets with the combustion air.

The patent specification DRP no. 532013 (1924) for Aero A.-G. Kussnacht (Switzerland) describes a pintle-type nozzle, with a specially formed pintle tip. The latter coacts with the nozzle orifice in such a manner that at varying needle lift the spray angle also varies. However, in actual operation the needle opens and closes rapidly; therefore during most of the injection the same spray angle will prevail. The equation of motion of the needle is investigated, and the question is posed whether a slowing down of the needle lift could be achieved by either: a) increasing the mass of the needle and of the adjoining valve elements, or b) by introducing a hydraulic damping. Both of these methods are investigated analytically, and it is concluded that only the method (b) is practicable. An experimental nozzle has been devised, incorporating hydraulic damping. The variation of the spray angle during the period of injection has been photographically determined by means of an optical arrangement devised by the author. While the experimental nozzle performs qualitatively in the intended manner, yet it needs further improvement—according to the author—in order to make it practically usable.

AMR 10-1151

P-45. Popov, V. F., and G. K. Goncharenko

"Ultrasonic Atomizers for Liquids and Melts." V. F. Popov and G. K. Goncharenko (V. I. Lenin Polytech. Inst., Kharkov). Izv. Vysshikh Uchebn. Zavedenii, Khim. i Khim. Tekhol. 8(2), 331-7 (1965) (Russ).

CA 63-12693b

P-46. Potts, S. F.

"Concentrated Spray Equipment, Mixtures, and Application Methods," 598 pp., Dorland Books, P.O. Box 31, Caldwell, N.J., 1958.

P-47. Potts, S. F.

"Particle Size of Insecticides and Its Relation to Application, Distribution, and Deposit," J. Econ. Ent. 39, No. 6, 716-20 (1946).

P-48. Poulston, B. V., and E. F. Winter

534. Poulston, B. V., and Winter, E. F., Techniques for the study of air flow and fuel droplet distribution in combustion systems, Sixth (International) Symposium on Combustion, New York, Reinhold Publ. Corp., 1957, 833-842.

Research into the fundamental processes of liquid fuel combustion concerns itself with homogeneous systems of idealized droplet systems to obtain basic combustion data. Actual combustion equipment uses far more complex systems. The techniques described in this paper deal with separate investigations of component processes of combustion systems, namely: flow pattern, fuel distribution, sizes of droplets produced by an atomizer. Air flow can be studied, with and without combustion, by a water-cooled three-dimensional pitot tube. Flow pattern can be studied in a water model by continuous light and by electronic flash. Residence time of a particle in any zone of the combustion chamber can be studied by injecting a single tracer particle of polystyrene globule with fluorescent coating, illuminated by ultraviolet light from a mercury discharge lamp, and photographing the trace in a time exposure. Fuel spray distribution can be studied by probes protruding into the spray for collecting the spray; the location of the probe entrance can be varied both axially and radially. These component factors and phenomena can be correlated with the actual combustion, and conclusions drawn for the effect of each factor on the efficiency of combustion.

AMR 12-534

P-49. Pozzi, A.

6536. Pozzi, A., Jets in a medium of different properties, *J. Aerospace Sci.* 29, 4, 471-472 (Readers' Forum), Apr. 1962.

This brief theoretical note is rendered extremely difficult to follow by what appears to the reviewer to be an abundance of misprints and undefined symbols and subscripts. However, to paraphrase the author's summary: The Schlichting model of a jet in a homogeneous medium at rest is known to lead to similarity solutions. This note shows that nonhomogeneity of the jet destroys the similarity, but that it is possible to obtain "nearly similar" solutions by linearizing the equations of diffusion and motion.

AMR 15-6536

P-50. Priem, R. J.

1238. Priem, R. J., Breakup of water drops and sprays with a shock wave, *Jet Propulsion* 27, 10, 1084-1087, 1093, Oct. 1957.

An apparatus for investigating the effect of shock waves on sprays is described and illustrated. Shock strengths of 1.32 (Mach number 1.13) were obtained in a test section at one atmosphere. High-speed pictures of 0.030 to 0.160-in. diam water drops show that the drops are broken up by the high-velocity gas behind a shock front. Small water jets were not affected by a shock wave. Photographs of impinging jets, parallel sheets, and parallel jet types of sprays also show that the breakup of sprays is accomplished by the high-velocity gas behind the shock front. The shock tube has two parts: (a) the "shock development" part is 4 ft long and 5 in. square; to this are adjoining the (b) four "detonation tubes" of ¾-in. diam; by this means, four shocks can be produced at specific intervals. The jets are produced by gas-pressurized water tanks. Pictures of sprays were obtained with a "Fastex" camera using shadowgraph technique. Shock velocities were measured with two piezoelectric pickups placed 12 in. apart and connected to an oscilloscope; time required for the shock to travel between pickups was measured from the film record of the oscilloscope trace. A large number of pictures of drops and jets are shown, and the critical diameters of drops and jets below which no breakup occurs are shown in graphs.

AMR 11-1238

P-51. Probert, R. P.

The Influence of Spray Particle Size and Distribution in the Combustion of Oil Droplets. R. P. Probert (Power Jets (R and D) Ltd., London). Phil. Mag. (Engl.) Vol. 37, No. 265 (Feb. 1946), pp. 94—105, 3 fig., 3 ref.

Detailed mathematical analysis of distribution of fuel in spray; evaporation and mean diameter of drops, as injected and as burned; mean diameter and specific volume in combustion; combustion intensity; incomplete evaporation; graphs are given for calculating the rate of spray evaporation and for showing how the liquid volume varies with time. Effect of destribution on combustion intensity; desirable spray characteristics for good combustion.

deJ I-272

P-52. Probst, R. L.

"Spherical Metal Powders--Production and Characteristics," pp. 45-47 in "New Types of Metal Powders," Metallurgical Soc. Conferences, Vol. 23, H. H. Hauser, editor. Gordon and Breach Science Pub. Co., Cleveland, 1964.

P-53. Probst, R. L.

"Production and Use of Spherical Metal Powders," Metal Progress, 107-10 (July, 1962).

P-54. Probst, R. L., et al.

"Atomizing Nozzle and Pouring Cup Assembly for the Manufacture of Metal Powders," U.S. Patent 2,968,062, March 23, 1959.

P-55. Prokonenko, S. P.

5306. **Prokonenko, S. P. The geometrical features of the centrifugal nozzles of sprinklers (in Russian),** *Sel'khozmashina* no. 1, 17-18, 1957; *Ref. Zh. Mekh.* no. 4, 1958, Rev. 3988.

The problem is examined of the centrifugal atomizer into the vortex chamber of which the flow enters at an angle to the plane section $\alpha_{inlet} \neq 0$. It is shown that the end formulas for this case have the same form as the case of α_{inlet} being equal to zero if the value

$$A = \frac{R_{inlet}\, r_c\, \pi \cos \alpha_{inlet}}{n f_{inlet}}$$

is taken for the geometrical characteristic of the centrifugal nozzles of the sprinklers. Here R_{inlet} is the distance from the longitudinal axis of the nozzles to the axis of the feeder channel, r_c the radius of the outlet nozzle, $n f_{inlet}$ the total area of all the flow inlets into the vortex chamber.

AMR 12-5306

P-56. Putimtsev, B. N., and Yu. A. Gratsianov

"Metal Powders." B. N. Putimtsev and Yu. A. Gratsianov, U.S.S.R. 125,458, Jan. 8. 1960.

CA 54-14081d

P-57. Putnam, A.

"Integrable Form of Droplet Drag Coefficient," ARS Journal 31, 1467-8 (1961).

P-58. Putnam, A. A., et al..

326. **Putnam, A. A., Bonington, F., Einbinder, H., Hazard, H. R., Kettelle, J. D., Levy, A., Miesse, C. C., Pilcher, J. M., Thomas, R. E., Weller, A. E., Landry, B., Injection and combustion of liquid fuels,** *WADC Tech. Rep.* 56-344, xxxii + 723 pp., 51 tables, 240 figs., 1100 ref.

This is a monumental monograph on the subject stated in the title, a work of many scientists, experts in their field, produced under the sponsorship of the United States Air Force, by the Battelle Memorial Institute. It is a critical review of unclassified literature relating to the physical phenomena involved in steady-flow process in high-intensity combustors. Intermittent sprays and their combustion, as in diesel engines, are not considered. For systematic treatment the subject is divided into six parts, subdivided into 19 chapters, under the following headings:

Part I. Atomization of liquid fuels:
- Chap. 1, The mechanism of atomization
- Chap. 2, Methods of atomization
- Chap. 3, Design of atomizers
- Chap. 4, Spray analysis

Part II. Ballistics of droplets:
- Chap. 5, Ballistics of a single droplet
- Chap. 6, Dynamics of dispersion

Part III. Evaporation of droplets:
- Chap. 7, Thermodynamics and kinetics of evaporation
- Chap. 8, Single droplet evaporation
- Chap. 9, Evaporation of a moving droplet
- Chap. 10, Spray evaporation

Part IV. Fluid Dynamics:
- Chap. 11, Equations of fluid dynamics
- Chap. 12, Turbulence
- Chap. 13, Hydrodynamic recirculation

Part V. Homogeneous Combustion:
- Chap. 14, Laminar flame propagation
- Chap. 15, Turbulent flames of premixed gases
- Chap. 16, Stability limits of premixed flames
- Chap. 17, Ignition of combustible mixtures

Part VI. Heterogeneous Combustion:
- Chap. 18, Droplet combustion
- Chap. 19, Diffusion flames

Each chapter is preceded by an abstract; this is followed by a list and summaries of the work of previous investigators, given in sufficient detail to dispense with the original papers. Then a critical summary is given, and the significant references and bibliographic data are listed. The Institute and the contributors have given their unstinted efforts to make this volume complete and up to date, rendering thereby a great service to workers in this field.

AMR 11-326

P-59. P'yankov, S. M.

"Theoretical and Experimental Investigations of Apparatus; Atomization Jet for Liquid Fuel (Heavy Fuel Oil)" (in Russian), Thesis, Moscow, Mosk. In-ta Inzh. Zh.-d transp., 1956; Ref. Zh. Mekh. No. 4, 1957, Rev. 4228.

R-1. Rabin, E., and R. Lawhead

"The Motion and Shattering of Burning and Nonburning Propellant Droplets," Rocketdyne, AFOSR TN-59-129, March, 1959.

R-2. Rabin, E., A. R. Schallenmuller, and R. B. Lawhead

"Displacement and Shattering of Propellant Droplets," Rocketdyne, AFOSR TR-60-75, March 1960.

R-3. Radcliffe, A.

"On the Performance of a Type of Swirl Atomizer," Trans. Instn. Mech. Engrs. 169, 93-106, (1955)

R-4. Radcliffe, A.

The Performance of a Type of Swirl Atomizer. A. Radcliffe (British National Gas Turbine Establishment). Institution of Mech. Engrs. (London), (1954), 10 p., 15 fig., 5 ref., 6 tables. (Previously published as Rep. No. 83, NGTE (Jan. 1951), 21 p., 24 fig., 5 ref.).

Parameters controlling the flow in swirl atomizers are: mass flow rate Q, fuel pressure P, fuel viscosity μ, fuel density ρ, and linear dimension of a swirl atomiser L. A relationship was found, by dimensional analysis, between $Q^2/L^4P\rho$ and $Q/\mu L$, which can be represented in a chart. This relation is valid for a variety of parameters used in the experiments. Effect of varying atomizer shape on fuel flow and on cone shape is also examined. For a non-spill atomizer spraying kerosene the Sauter Mean Diameter of drops is equal to 323 $Q^{[illegible]}/P^{[illegible]}$ where Q is measured in lb/hr and P in lb/in². It is shown that as the spill line is opened the spray particle size decreases. Based on the equations and charts the effect on flow of varying atomizer shape can be predicted. Seven liquids: carbon tetrachloride, gasoline, kerosene, and four mixtures of kerosene and of hydraulic oil, were used, having a density range of 0.75 to 1.6 gramme per cm³., and a viscosity range of 0.5 to 25 centipoises; the pressure range was 5 to 1000 psi.

deJ I-281

R-5. Radcliffe, A., and H. Clare

A Correlation of the Performance of Two Air Blast Atomizers with Mixing Sections of Different Size. A. Radcliffe and H. Clare (National Gas Turbine Establishment, Pyestock, Hants, England). Rep. No. 144 (Oct. 1953), pp. 19, 20 fig., 3 ref.

Experiments on air blast atomizer; effect of increasing the orifice diameter. Show that the main factor controlling atomization is the air: fuel ratio; when this is 0.1 the Sauter Mean Diameter is about 100 microns (for a fuel of 20 to 40 centistokes viscosity). Droplet size increases approx. proportionally to the square root of linear dimensions of the orifice and the mixing section.

deJ I-281

R-6. Raillères, R., and A. Avy

"A New Method for the Fine Atomizing of Liquids." Raymond Raillères and Alban Avy. Mém. services chim. état (Paris) 39, 113-18 (1954).

CA 50-16195h

R-7. Rammler, E.

Zu den Gesetzmäßigkeiten in der Kornverteilung zerkleinerter Stoffe (On the Laws of Particle Distribution of Comminuted Materials). Erich Rammler. (Bergakademie Freiberg, Sachsen, East Germany). „Forschungen und Fortschritte", Vol. 30, No. 1 (Jan. 1956), pp. 1–9, 13 fig., 59 ref.

Significance of particle-distribution curve and formula for describing the main characteristics of comminuted materials. Survey of theoretical work and detailed exposition of the Rosin-Rammler-Sperling (RRS) formula. This formula has been developed primarily for powdered coal and other milled materials, but it is applicable also to chips produced by turning, milling and grinding operations, and also to drop-size distribution in liquid sprays. The RRS formula represents the weight residuum of a population (of particles, dusts, drops) as ordinate, over the size of the particle (a length dimension) as abscissa. The coordinates are in log, resp. log log scale. There are recent attempts to use, as ordinate, not the weight, but the surface area, in order to emphasize the main purpose of comminution, i. e., the increase of the surface area. Survey of a large number of research work in this field made by the author and by others.

deJ I-283

R-8. Rammler, E.

Spezielle Logarithmentafel log (log 100/R) – f (R) für RRS-Kornverteilungen (Special logarithm table log (log 100/R) – f (R) for RRS-particle distributions). Erich Rammler (Bergakademie Freiberg, Sachsen). Freiberger Forschungshefte No. A 40 (1955), pp. 5–12, 1 fig., 3 ref.

The grain-size distribution formula of Rosin, Rammler and Sperling (RRS-formula)

$$R = 100\, e^{-(d/d')^n}\ \%$$

in which R is the residuum (i. e., the proportion of weight of all grains larger than, or equal to d), d is the grain size and d' and n are comminution parameters, can be represented, by means of two successive logarithm operations, as a linear relationship:

$$\log (\log 100/R) = C + n \log d$$

Author calculated and tabulated the quantity on the left side of the equation for R-values between 0 and 100 in increments of 0.1. Using this table in conjunction with a chart having log d as abscissa and log log 100/R as ordinate the characteristic quantities n and d' can be readily obtained.

While the RRS (Rosin-Rammler-Sperling) formula and the present method of evaluation have been worked out mainly for comminuted solid materials, as powdered coal and other milled goods, they are usable also for atomized liquids.

deJ I-282

R-9. Randell, J. M.; W. R. Marshall and J. L. Tschernitz

"The Atomization of Liquids by High Voltage Electrical Energy," presented at AIChE Meeting, Las Vegas, Nevada, Sept. 22, 1964.

R-10. Ranz, W. E.

3464. Ranz, W. E., Some experiments on the dynamics of liquid films, *J. Appl. Phys.* 30, 12, 1950-1955, Dec. 1959.

Two liquid film phenomena are investigated: (a) a soap film formed inside a circular ring is ruptured at its center, the rupture spreading in a circular form toward the anchored edges, and (b) a circular liquid sheet is formed by two equal-velocity water jets impinging against one another. The two phenomena are dynamically inverse to each other. For phenomenon (a) it is found on theoretical grounds (Rayleigh) that the ruptured edge moves outward at a speed constant with time and position; this is confirmed by experiment. Soap film thickness is measured by reflected color, light absorption, and static surface contour under the effect of gravity; it is found that thickness of film is not constant, and that it has an uneven surface. Methods of rupturing the film are described: by a sharp needle, by absorbent points, and by electric spark; the last method was found the most reliable provided the spark was continued long enough. Film-edge velocity was measured by double-image photographs, and also by repeated exposures with a Fastax camera. Results show that the ruptured film rolls up without thickening of the yet unconsumed film because the velocity of elastic wave is considerably less than the velocity of the free edge.

For phenomenon (b) the energy balance equation is stated from which the film thickness at a given radius is calculated. With consideration of mass balance and a momentum balance the velocity at the edge and the thickness of the film entering the edge are calculated; results are not in good agreement with experimental values. Author discusses nonsymmetrical films produced by jets impinging at a sufficient angle between the jets to give a spray sheet in one direction only. He compares phenomenon (b) to spraying from rotating disk.

This concise paper clarifies some of the basic factors in spray formation and fundamental equations related to it.

AMR 13-3464

R-11. Ranz, W. E.

3134. Ranz, W. E., Some experiments on orifice sprays, *Canad. Chem. Engng.* 36, 4, 175-181, Aug. 1958.

This is a report on a systematically planned experimental investigation based on theoretical considerations, mainly of dimensional analysis and of the principle of similitude.

New approaches to studies of spray systems were demonstrated by a series of experiments using liquid jets of mercury and of carbon tetrachloride spraying in water. Using water (instead of air) as the ambient medium is a novel method of slowing down the spray phenomena and thus making it easier to observe and photograph them. Attention was focused on those conditions in which the stresses causing break-up arose from the inertia of the surroundings, and in which the induced motion of the surroundings controlled the characteristics of the spray zone in front of the orifice. Experiments and analysis involved principle of balanced stresses, dispersion angle, motion of induced phase, development of spray zone, and drop size. Impact stresses and shear stresses acting between the ambient and the disperse phase are expressed mathematically in physical terms. Photographs of mercury spray and carbon tetrachloride spray in water are shown. Experimental equipment is illustrated and described; photomicrographs of sprays are shown, with size-distribution charts derived from them.

AMR 12-3134

R-12. Ranz, W. E

"The Principle of Balanced Stresses and the Mechanical Formation of Aerosols," pp. 7-16 in "Spray Dissemination of Agents," Report of Symposium VIII, Vol. I, Conducted by U.S. Army, CWL, March 4-6, 1958.

AD 205196

R-13. Ranz, W. E.

5242. Ranz, W. E., On sprays and spraying, Dept. Engng. Res. Penn State Univ. Bull. 65, 75 pp. + 20 figs., 1956.

Survey evaluates and interprets present-day information on sprays for research and development engineers concerned with the science and technology of sprays. Spray phenomena involve complicated physical processes influenced by many variables. The survey is organized under three headings:

I. Characteristics of sprays, including: drop sizes, representation of size distributions, sampling and sizing methods for measuring drop sizes, rapid sizing methods, and standardizing test methods for drop sizes;

II. Mechanics of drops and sprays, including: mechanics of single drops, terminal velocities, acceleration and deceleration of single drops and ultimate stopping distance, impaction of drops, and definition of dispersion and penetration;

III. Important variables affecting breakup of jet, including: surface tension, viscosity, liquid sheets, liquid filaments, gas atomization, dimensional analysis of quantities governing spray phenomena, and evaluation of theories concerning jet breakup.

The text is clarified by numerous charts and equations.

This survey provides a logical framework for the study of spray phenomena within which other information can be systematically organized.

AMR 11-5242

R-14. Ranz, W. E., and C. Hofelt

2187. Ranz, W. E., and Hofelt, C., Determining drop size distribution of a nozzle spray, *Indust. Engng. Chem.* 49, 288-293, 1957.

Because a rapid and routine method is needed for measuring drop-size distributions in sprays, a rectangular jet impaction system was developed as a test apparatus for obtaining cumulative volumes versus drop sizes in sprays.

Inertial impaction theory was the basis for design of equipment and analysis of test data. A test stand, scaled to the order of 10 ft, was built to measure drop sizes of the order of 100 microns. The special flow system, test procedures, and experience with actual sprays from domestic oil burner nozzles are described. The impacter constructed for development tests gave a relative measure of spray drop sizes in the range of 60 to 90 microns. A larger apparatus can be designed for analyses of sizes up to 150 microns.

AMR 11-2187

R-15. Rao, M. N.

"Flow Pattern and Mechanism of Atomization in Pressure Nozzles," J. Sci. Eng. Res (India) 4, 239-50 (1960).

R-16. Rao, S. P., and R. Kaparthi

23856 STUDIES IN DROP FORMATION AT NOZZLE TIPS.
P.Sadasiva Rao and R.Kaparthi.
Indian J. Technol., Vol. 1, No. 5, 189-92 (May, 1963).

The drops formed at nozzle tips have been observed to be always followed by a smaller drop, the Plateau's spherule. The diameter of the spherule is a function of the drop diameter, interfacial tension and the difference between the densities of the drop liquid and the continuous medium. On the basis of the data obtained for 10 liquids with widely varying physical properties and using 10 nozzles of different diameters, the following correlation has been worked out for predicting the spherule diameter for a given drop diameter: $D(\Delta\rho/\sigma)^{0.5}$ = 0·06728 exp. 4·6d where D is the equivalent spherical diameter of the drop; $\Delta\rho$ the difference between the densities of the continuous medium and the drop liquid; σ the interfacial tension, and d the diameter of the spherule.

PA 66-23856

R-17. Rapaport, E., and S. E. Weinstock

"A Generator for Homogeneous Aerosols." E. Rapaport and S. E. Weinstock (Ministry of Defense, Tel Aviv, Israel). Experientia 11,368-4 (1955) (in English).

CA 51-2329c

R-18. Rasbash, D. J.

The Properties of Sprays Produced by Batteries of Impinging Jets. D. J. Rasbash (Fire Res. Station, Boreham Wood, Herts., Engl.). Dep. Scie. and Ind. Research and Fire Offices' Comm. Joint Fire Res. Organization. F. R. Note No. 181/1955 (May 1955) (Mimeogr.), 7 p., 3 fig., 6 ref.

The entrained air velocity, mass median drop size, drop-size distribution and drop velocity of sprays falling on a given area, produced by a battery of impinging jets, have been related to the diameter of the jets, the pressure at the jets, and the rate of flow to a given area. Formula has been derived for predicting the entrained air velocity in the sprays which agrees fairly well with the formula. Application of the theoretical formula to predict the entrained air velocity and reach of sprays from single pressure nozzles is discussed. Finds that rate of reduction in drop size with increase of pressure decreases as pressure is increased. Mass median drop size was determined from samples of spray comprising 2500 to 10000 droplets; drop-size distribution was found to agree fairly with Rosin-Rammler law. Charts are given representing: (1) velocity of drops in excess of velocity of entrained air vs. drop size, (2) exponent of pressure vs. drop size, and (3) ratio of mass-median drop diameter to jet diameter, vs. Reynolds number at the jet.

deJ I-287

R-19. Rasbash, D. J.

6525. The production of water spray of uniform drop size by a battery of hypodermic needles. D. J. RASBASH. *J. sci. Instrum.*, **30**, 189-92 (*June*, 1953).

The assembly of a spray apparatus consisting of 169 hypodermic needles is described. This apparatus could give a concentrated flow of spray at a wide range of drop sizes and rates of flow. In the range of drop size 0·6-2·4 mm the drop size uniformity of the spray was much better than could be obtained by pressure nozzles. Coalescence of the drops while falling, however, was a factor which decreased the uniformity as compared with drops falling from a single needle.

PA 56-6525

R-20. Rasbash, D. J., and G. W. V. Stark

"Control of the Distribution of a Spray Projected to an Area," J. Sci. Instr. 34, No. 2, 75-6 (Feb. 1957).

R-21. Rayleigh, Lord

Scientific Papers by John William Strutt (Baron) Rayleigh. Cambridge University Press. Cambridge (Engl.). 1920.

Contains several papers concerning flow of fluids, dealing with, or touching on the formation of sprays.

deJ I-290

R-22. Rayleigh, Lord

On the Instability of a Cylinder of Viscous Liquid under Capillary Force. Lord Rayleigh (John William Strutt). Phil. Mag. (Publ. Taylor and Francis, London) 5th series, Vol. 34, No. 207 (Aug. 1892), pp. 145–154.

Based on the theory of Plateau author considers the problem of dynamic stability of a jet assuming that the resistances are proportional to the absolute velocities of the parts. Refined mathematical treatment showed a marked difference between this case and that of a filament whose distintegration is resisted by true fluid viscosity. Considers cases when viscosity is very great in comparison with inertia; also, when the wave length of "varicosity" is very small in comparison with the jet diameter; and the subsidence of waves on the surface of a highly viscous material. (This is a sequel to RAYLEIGH 1879.)

deJ I-290

R-23. Rayleigh, Lord

On the Tension of Water Surfaces, Clean and Contaminated, Investigated by the Method of Ripples. Lord Rayleigh. Phil. Mag., London, Ser. 5, Vol. 30, Nov. 1890, pp. 386–400, 1 fig., 3 tabl., 10 ref. (no titl.).

Tension of water surface is reduced by the presence of even a trace of grease. In case of olive oil, a film of 2 micro-millimeter calculated thickness is sufficient to alter the properties of a surface in relation to fragments of camphor floating thereupon. Investigates tension of greasy surfaces. Refers to RAYLEIGH 1890.

deJ II-324

R-24. Rayleigh, Lord

On the Tension of Recently Formed Liquid Surfaces. Lord Rayleigh. Proc. Royal Soc., London, Vol. 47, March 6, 1890, pp. 281–287, 3 fig., 4 ref. (no titl.).

"It has long been a mistery why a few liquids, such as solutions of soap and saponine, should stand so far in advance of others in regard to their capability of extension into large and tolerably durable laminae." Refers to work of Plateau, and of Marangoni according to whose theory the body of the liquid is coated with pellicles composed of matter whose inherent capillary force is less than that of the mass. Describes experiments on a liquid jet issuing under moderate pressure from an elongated, e.g., elliptical, aperture, perforated in a thin plate, and which assumes a chain-like appearance, the wave length of which, corresponding to two links of the chain, corresponds to the distance traveled over by a given part of the liquid in the period of complete transverse vibration of the column about its cylindrical configuration of equilibrium. Illustrates and describes the experimental arrangement; tabulates experimental data for water, and for water-oleate mixtures of various proportions. The value of surface tension can be calculated from the wavelength, which can be measured on photographs taken from the jet.

deJ II-324

R-25. Rayleigh, Lord

On the Theory of Surface Forces. Lord Rayleigh. Phil. Mag., London, Ser. 5, Vol. 30, Oct. 1890, pp. 285–298; 456–475, 15 fig., 61 equ., 21 ref. (no titl.).

Reviews previous work by Laplace, Young, Maxwell, Worthington, Gauss (surface energy), Boltzmann, William Thomson, and some others. Gives detailed mathematical theory, based on Laplace's work on mutual attraction of liquid particles through a very small range. Then exhibits another calculation which permits extension of formulae. Discusses Fuchs's work on tension of curved surfaces, on pressures at the center and upon the surface of a spherical mass of fluid surrounded by vacuum. Treats wetting and non-wetting fluids; oil spreading on water (in a layer of about 2×10⁻⁹ mm) and coalescence of layer into lentiform discs. Interprets these phenomena in terms of capillarity theory.

deJ II-324

R-26. Rayleigh, Lord

On the Equilibrium of Liquid Containing Masses Charged with Electricity. Lord Rayleigh. Phil. Mag., 5th Ser., Vol. 14, Sept. 1882, pp. 184-186, 1 ref.

Owing to electrical repulsion a charged spherical mass of liquid, acted upon by other forces, is in a condition of unstable equilibrium. Calculates, by actual mathematical method, the electrical voltage necessary to render a small water drop of 1 mm. dia. unstable; finds this is about the voltage of 5000 Daniell cells.

deJ II-323

R-27. Rayleigh, Lord

Further Observations upon Liquid Jets. Lord Rayleigh. Proc. Royal Soc. London, Vol. 34, June 1882, pp. 130-145, 6 fig.

Continuation of RAYLEIGH 1879A and 1879B, deadlines some of the circumstances which influence the scattering of a nearly vertical jet of liquid; influence of regular vibrations of low pitch (production of multiple jets); length of the continuous part; collision of two resolved streams (two streams of drops from the two broken-up jets are brought into collision at an acute angle; the two sets of drops first coalesce, then separate again and continue in their paths as if no coalescence had occurred); influence of electric charge by passing the jet between two charged plates; collision of streams before resolution. Treatment is wholly experimental, without theory and mathematics. Experiments were made with water, glycerine, sugar solution, gum arabic, alcohol, and sulphuric acid.

deJ II-323

R-28. Rayleigh, Lord

On the Instability of Jets. Lord Rayleigh (John William Strutt). Proc. London Math. Soc. (Engl.), Vol. 10 (1878/79), pp. 4--13.

Fundamental mathematical analysis of the conditions for the breaking up of a liquid jet. Assumes a disturbance symmetrical about the jet axis; calculates the change of potential energy (due to surface tension), and of kinetic energy (due to motion of liquid), caused by the disturbance. Finds that a wave length of "varicosity" equal 4.51 times the jet diameter leads most rapidly to the disintegration of the cylindrical mass. Refers to the work of Plateau, Savart, Thomson and Helmholtz. Treats also the influence of friction caused by the motion of the jet within a medium (gas or liquid). This work served as basis for most subsequent theoretical researches on sprays by later investigators.

deJ I-289

R-29. Rayleigh, Lord

"On the Capillary Phenomena of Jets," Proc. Roy. Soc. 29, 71-97 (1879).

R-30. Rayleigh, Lord

The Theory of Sound. Lord Rayleigh (John William Strutt). Dover Publications, Inc. New York 19, N.Y.

Chapter XI. p. 360 deals with breakup of liquid column. (Cited in TYLER 1033.)

deJ I-290

R-31. Rayner, A. C., and W. Haliburton

955. **ROTARY DEVICE FOR PRODUCING A STREAM OF UNIFORM DROPS.** A.C.Rayner and W.Haliburton. Rev. sci. Instrum., Vol. 26, No. 12, 1124-7 (Dec., 1955).

A rotary device was developed to produce uniform drops of liquids in the diameter range of 50 to 700 microns. A horizontally rotating blade detaches drops in a steady stream of regular trajectory, from a stabilized liquid mass fed under constant head through a stationary capillary. Its operation is described, and performance characteristics with oil and aqueous test solutions are given. Drop size is calculated from the mass of drops emitted in a given interval at a known generation frequency. Variation in size of individual drops, electrostatic effects, and some uses for the machine are noted.

PA 59-955

R-32. Rayner, A. C., and H. Hurtig

"Apparatus for Producing Drops of Uniform Size." A. C. Rayner and H. Hurtig (Dept. Agr., Ottawa, Can.). Science 120, 672-3 (1954).

CA 49-50311

R-33. Reed, W. H.

2250. **Reed, W. H., III, An analytical study of the effect of airplane wake on the lateral dispersion of aerial sprays,** *NACA TN* 3032, 46 pp., Oct. 1953.

The trajectories of spray droplets discharged from an airplane wing were obtained by numerical integrations of the equations of motion, treating the flow field in the vicinity of the wing as a vortex system. Motion and decay of the vortex system and deviations from Stokes law were taken into account.

For ejection of a given spectrum of droplets at a single point on the wing, it was found that the lateral dispersion of spray deposition on the ground increased with altitude and lift coefficient, and when the point of ejection was moved toward the wing tip.

With spray discharged uniformly along the wing the ground deposit was a maximum at the plane of symmetry and rapidly decreased beyond the wing tip. Uniformity and effective width of ground deposition were improved by increasing the spray mass rate with spanwise distance. Decreasing the mean drop size gave better uniformity of deposit for given flight-path spacing.

AMR 7-2250

R-34. Reményi, K.

"Theoretical Investigation of Atomizers and Main Principles of Their Operation," Energia és Atomtechnika (Budapest) 12, No. 10-11, 696-8 (1959).

R-35. Retel, R.

Contributions a l'Etude de l'Injection dans les Moteurs Diesel (Contributions **to the study of Diesel** Injection). R. Retel. Min. de l'Air (France) Bull. Serv. Techn. No. 3[1] (1933), 63 p.

Drop size measurements using catching methods. Effect of orifice design, injection **pressure, air density on atomization.** Mechanism of disintegration. Application to nozzle **design. Effect of atomization on engine** performance.

deJ I-291

R-36. Reure, C. M. R., and F. G. Paris

"Smoke, Fog, or Aerosol Generator," U.S. Patent 2,836,567, May 27, 1958.

R-37. Reynolds, J. M.

7924 STABILITY OF AN ELECTROSTATICALLY SUPPORTED FLUID COLUMN. J. M. Reynolds.
Phys. of Fluids (USA), Vol. 8, No. 1, 161-70 (Jan. 1965).

An analytical and experimental study has been made of the cylindrical interface between two dielectric liquids under the influence of electrostrictive forces and surface tension. The analysis indicates that, for "high"-frequency applied fields such an interface can be stable. For stability, the applied voltage must be great enough to suppress tension effects and lower than some analytically determined critical value. For voltage greater than this critical value, experiments indicate that the interface is deformed in an unusual manner.

PA 68-7924

R-38. Richardson, E. G.

Book—3044. Richardson, E. G., edited by, Aerodynamic capture of particles (Proceedings of a Conference held at British Coal Utilization Research Association, Leatherhead, Surrey, England, 1960), London, Pergamon Press, 1960, 200 pp. + figs. $8.

This conference dealt with the broad subject indicated in the title in three sessions, each comprising five papers, treating: (1) theoretical and fundamental aspects, (2) experimental applications of capture techniques, and (3) capture of particles by raindrops. The aerodynamic capture of particles concerns meteorological problems such as icing of aircraft wings and of motor car windshields, microbiological warfare and atomic fallout, and also a variety of industrial processes such as fish-curing by smoke, froth flotation, and erosion of turbine blades.

Titles of papers presented in the three sessions follows: I. Historical survey; Dust deposition from a turbulent airstream; Classical computation of the aerodynamic capture of particles by spheres; Particle trajectories, collision, and attachment in froth flotation; Electric charge effects in aerosol particle collision phenomena. II. Aspects of deposition of radioactive and other gases and particles; Size of wood-smoke particles; Impingement of water drops on a surface moving at high speed; Distribution of impacted particles of various sizes on the blades of a turbine; Role of diffusion, interception, and inertia in the filtration of airborne particles. III. Suppression of airborne dust by water spray; Theoretical collision efficiency of small drops; Collection efficiencies for water drops in air; Scavenging action of rain on non-wettable particulate matter suspended in the atmosphere; Laboratory experiments relating to the wash-out of particles by rain.

The authors are recognized authorities on their subjects; each paper lists pertinent references (though this reviewer would have liked the inclusion of the titles of the references in addition to the bibliographic data). In a rapidly developing and proliferating field, such as that of drops, particles and sprays, a treatise by symposium (as in the present case) is often preferable to a treatise by monograph. In the organization of the present symposium, selection of topics and authors, the chief organizer and editor, the late Professor Richardson, merits great credit.

AMR 15-3044

R-39. Richardson, E. G.

1194. Richardson, E. G., Mechanism of the disruption of liquid jets, *Appl. sci. Res.* (*A*) 4, 5/6, 374-380, 1954, 3 figs., 9 refs.

Photographs of a water jet issuing from a straight nozzle are obtained with microflash illumination, at varying flow velocities. Three regimes of flow can be distinguished, each of which results in a special type of breakup into drops. At the lowest velocity, first investigated by Rayleigh, capillary ripples develop on the liquid surface, causing the cylindrical surface to become "varicose," resulting ultimately in breaking up of the jet into discrete drops. At higher velocity, a sinuous oscillation ("waggling") of the cylinder axis sets in, like the thongs of a whip. At still higher speeds the friction of the air along the periphery of the jet causes the piecemeal disintegration of the jet, aided probably by turbulence within the nozzle. The second and third stages are discussed, referring to Weber's formula for the air friction of the jet, to Prandtl's boundary-layer parameter, and to the pertinent work of Lane, Merrington, and Hinze.

AMR 8-1194

R-40. Richardson, E. G.

Liquid Sprays. E. G. Richardson (Dep. Phys., King's Coll., Newcastle upon Tyne, Engl.). Chapter in HERMANS 1953, pp. 266-293, 17 fig., 6 tabl. numerous ref. (no titl.).

Treats: breakup of a liquid jet (varicose breakup, sinuous breakup, anomalies when jet length is small, peculiar liquids, bursting process); measurement of drop size (measuring technique, summation and distribution curves); drop size in liquid sprays (initial sizes, ultimate sizes, breakup of large drops, breakup of liquids by large accelerations); evaporation of aerosols (theoretical aspects); evaporation of freely falling drops; measurement of convective evaporation of drops.

deJ II-329

R-41. Richardson, H. L.

"Aspirator for Dispersing High-Boiling Liquids in Gases," U.S. Patent 2,598,304, May 27, 1952.

R-42. Richardson, J. F., and E. R. Wooding

12729* A Photographic Method of Analysing Aerosols. J. F. Richardson and E. R. Wooding. *Journal of Photographic Science*, v. 4, May-June 1956, p. 75-78.

The variation in size and concentration of particles in an aerosol over short periods of time was determined by a photographic technique in conjunction with a slit ultramicroscope.

BMI 5-12729

R-43. Riddell, F. R.

1412. Riddell, F. R., The jettisoning of liquids from an airplane in flight, *Douglas Aircr. Co. Rep.* SM-18279, v + 62 pp., 23 figs., 4 refs., Mar. 1954.

The problem of how to jettison fluids from an airplane in flight so as to avoid contamination of the aft section is discussed. Main physical factors and influencing features are investigated to find a rational approach to nozzle design. Results of some simple experiments and discussion of difficulties of model testing are given.

The process of formation and spreading of the spray of liquid drops may be described as follows: (1) The instability of small disturbances at the liquid-air interface causes a rapid disintegration of the liquid jet. (2) A mixing region comes into being in which the liquid drops and the local airstream interchange momentum until a mean velocity is reached. (3) Downstream of the mixing region the spray has the character of an ordinary wake, except for the inclusion of liquid drops. In the mixing region the spray shape can be changed considerably by changes of nozzle geometry. The wake region, however, can be controlled most effectively by changes in the flow rate of the liquid. Tentative parameter ranges are established to determine the relative importance of these regions under different conditions, whereby a basis for nozzle design and model testing is provided.

A detailed mathematical theory is given: (1) Of the dynamic instability of a liquid jet; (2) of the motion of a drop of liquid ejected laterally into an airstream; and (3) of the spreading of the wake.

AMR 8-1412

R-44. Riley, N.

1633. Riley, N., Asymptotic expansions in radial jets, *J. Math. Phys.* 41, 2, 132-146, June 1962.

The purpose of this paper is to investigate the effects of departures from similarity on the solution of the boundary-layer equations for flow in radial jets by finding how many terms in the asymptotic expansion of the solution are provided by the general similarity solution. The radial free jet, radial wall jet and radial liquid jet are considered, but the methods employed are also applicable to the two-dimensional analogs of these jets.

AMR 16-1633

R-45. Ríus, A., et al.

"The Spraying of Liquids by Centrifugal Disks. I. Size of the Drops and the Process Variables." A. Ríus, J. L. Otero de la Gandara, and P. Luis y Luis (Univ., Madrid). Anales real soc. espan. fís. y quím. (Madrid) 53B, 73-86 (1957) (English summary).

CA 51-12562i

R-46. Roller, P. S.

Law of Size Distribution and Statistical Description of Particulate Materials. P. S. Roller. Jl. Franklin Inst., Vol. 223 (1937), pp. 609–633, 3 fig., 11 ref.

Describes a new law of size distribution of the form $y = a x^{\frac{1}{2}} e^{-\frac{b}{x}}$ in which a and b are parameters, e the base of natural logarithm, x the particle size, and y the weight in per cent of all material smaller than size *x*. Carefully obtained data on several particulate materials (cements, pigments, kaolins, clays and other ceramic materials) show that regressive characteristic of the curve signifies a non-equilibrium reduction in the coarse size range, while a convex or concave characteristic signifies the presence of a mixture of independent components in the material. True values of surface area, number of particles, and coefficients of uniformity are obtainable in terms of the two fundamental distribution parameters.

deJ I-294

R-47. Romp, H. A.

Oil Burning. H. A. Romp. Nijhoff, The Hague (Holl.), 1937, 336 p., 262 fig., 7 separate charts.

Ch. I, "The Historical Development of Oil Burning" contains numerous figures and descriptions of atomizers of all types. In Ch. II, "Basic Principles", the combustion of fuel in oil burners is treated in detail (intermittent oil flames in reciprocating engines are the subject of one chapter). Ch. III, "Modern Forms of Construction of Oil Burning Devices", deals with pressure atomization, principles, theories, design and performance of nozzles, also methods of measuring atomization. Other chapters treat air and stream atomizers. Ch. IV, "Future Development of Oil Burning", is concerned chiefly with applications of oil burners to heating plants, etc.

deJ I-294

R-48. Root, M. J.

"Aerosol Spray Patterns." Morris J. Root. Am. Perfumer Aromat. 70, No. 1, 50-1 (1957).

CA 51-13319i

R-49. Rose, W. G.

"Generation of a 'Strongly' Swirling Jet and Preliminary Experiments on the Effect on Its Development of Initial Swirl Distribution," AFOSR 2552 (Johns Hopkins Univ., Dept. Mech., Contract AF 49(638)-248), 20 pp. + figs., June 1962.

R-50. Rosenthal, A. H.

Device for Dispensing Liquid Fuel Into Combustion Air or Furnace. Adolph H. Rosenthal. U.S. Pat. 2,481,620, Sept. 13, 1949.

A nozzle is described, intended mainly for an oil-fired furnace, comprising two concentric tubes; an inner one for the liquid fuel, and an outer one for air. Mixing of liquid and air takes place at the open ends of the two tubes. On the inner tube ultrasonic vibration is imposed by magnetostrictive forces. The inner tube is built of ferromagnetic material; it is surrounded by an electromagnetic coil which is energized with alternating current. Thereby a rapidly alternating dilatation and contraction is produced on the inner tube, and its free end is excited into rapid axial vibration. The frequency of alternating current must be attuned to the natural frequency of vibration of the inner tube.

deJ I-296

R-51. Rosenthal, A. H.

Apparatur for Dispensing Liquid Fuel. Adolph H. Rosenthal. U.S. Pat. 2,453,595, Nov. 9, 1948.

Liquid fuel is atomized and mixed with air by means of ultrasonic vibration produced by a piezoelectric vibration generator. Vibratory element has an exposed surface on which a layer of fuel rests or, in another design, the fuel is sprayed onto it in the form of a coarse spray or jet.

deJ I-296

R-52. Rosin, P., and E. Rammler

The Laws Governing the Fineness of Powdered Coal. P. Rosin and E. Rammler. Jl. Inst. Fuel (Engl.), Vol. 7 (1933), pp. 29–36, 13 fig., 7 ref.

Mathematical investigation of size distribution in powdered coal, and in pulverized materials generally; fineness characteristics, and distribution curve. From probability considerations the following formula is derived: The quantity remaining on a sieve is $R = e^{-bx^n}$, in which b and n are parameters, x particle size and e is the base of natural logarithm. This formula is applied to experimental results and the range of parameters b and n is investigated. Conclusion: that it is universally valid for all powders, irrespective of the nature of material and the method of grinding.

deJ I-296

R-53. Rozenberg, L. D., and O. K. Eknadiosyants

Rozenberg, L. D. and Eknadiosyants, O. K.
KINETICS OF ULTRASONIC FOG FORMATION.
[1961] [7]p. 5 refs. [DSIR LLU]M. 3255.
Order from OTS or SLA $1.10 61-27615

Trans. of #Akusticheskii Zhurnal (USSR) 1960, v. 6, no. 3, p. 370-373.

DESCRIPTORS: *Fog, Production, *Ultrasonics, Liquids, Atomization, Surface tension.

Observations of fog formation in a small ultrasonic fountain showed that the fog is thrown off by separate portions (explosions) of a duration of 400 μsec.; the intervals between explosions are of considerable duration. The ejections may be narrow, directional or wide. The process of fog formation is always preceded by a lightening of the drops ("beads") of the fountain which are deformed after ejection.

T7-170

R-54. Rumscheidt, F. D., and S. G. Mason

"Breakup of Stationary Liquid Threads," J. Colloid Sci. 17, 260-9 (1962)

The break-up of long uniform liquid threads, suspended at rest in an immiscible viscous liquid, by the development of stationary symmetrical capillary waves is described. The wavelengths and rates of growth of the disturbances for systems having a range of viscosity ratio (thread liquid):(suspending liquid) from 0.03 to 6.7 showed good agreement with Tomotika's theory. When surface-active agents were present, there was some deviation from the theory, presumably from the development of a viscoelastic interfacial film.

Author

R-55. Rumscheidt, F. D., and S. G. Mason

"Particle Motions in Sheared Suspension XII, Deformation and Burst of Fluid Drops in Shear and Hyperbolic Flow," J. Colloid Sci. 16, 238-261 (1961).

R-56. Rupe, J. H.

"A Correlation Between the Dynamic Properties of a Pair of Impinging Streams and the Uniformity of Mixture--Ratio Distribution in the Resulting Spray," Jet Propulsion Lab., Calif. Inst. of Tech., Prog. Report No. 20-209, 1956.

R-57. Rupe, J. H.

"The Liquid-Phase Mixing of a Pair of Impinging Jets," Calif. Inst. Tech., J.P.L. Prog. Rpt. No. 20-195, Aug. 6, 1953.

R-58. Rupe, J. H.

"A Semi-automatic, Size Differentiating Droplet Counter," Cal. Inst. Tech., J.P.L. Prog. Report 20-162, 28 pp., Feb. 26, 1952 (ATI No. 148916).

R-59. Rupe, J. H.

"Critical Impact Velocity of Water Droplets as a Problem in Injector Spray Sampling," Jet Propulsion Lab., Calif. Inst. Tech., Progress Rept. No. 4-80. ATI No. 96420, 16 pp., Sept. 29, 1950.

R-60. Rupe, J. H.

"A Technique for the Investigation of Spray Characteristics of Constant Flow Nozzles," Third Symp. on Combustion, Flame, and Explosion Phenomena, pp. 680-694, The Williams & Wilkins Co., Baltimore, 1949.

Drop size investigation on water sprays from aircraft type combustion heater nozzles by means of glass collecting cells which are photographed at 50X magnification. The water is colored black, the cells are made non-wetting by means of a silicone compound, the immersion fluid is kerosene or Stoddard solvent. The cells are photographed in monochromatic light giving perfectly white discs against a black background as drop images on the negative. A fully automatic, electronic counter scans the drop images by means of 7 photocells giving accurate drop counts by 14 size groups down to 5 microns, enabling one man to make in 5 days a complete test run for one nozzle, comprising 395 drop samples. Information on photographic procedure, non-wetting agents, immersion fluids, principle of counter but not on its construction. Measurement of fuel distribution within spray. The Supplement gives experimental data on effect of viscosity, surface tension, and distance on drop size distribution and mean drop diameter; these data are used to predict the combustion performance of actual fuels in terms of per cent burned in flame front region, and distance required to complete combustion. Data on effect of liquid characteristics, air velocity, etc. on distribution and spray angle.

Author

R-61. Ryan, N. W.

"Mixing and Atomization by Impingement of Unconfined Liquid Jets," Mass. Inst. Tech., Dept. Chem. Engr. D. Sc. Thesis, Dec. 30, 1948.

R-62. Ryley, D. J.

"Electrical Method for Detection of Transition of Atomization Type in Centrifugal Atomizers," J. Sci. Instr. 36, 243-4 (May 1959)

R-63. Ryley, D. J.

6755 **ANALYSIS OF A POLYDISPERSE AQUEOUS SPRAY FROM A HIGH-SPEED SPINNING DISK ATOMIZER.**
D.J.Ryley.
Brit. J. appl. Phys., Vol. 10, No. 4, 180-6 (April, 1959).

The analysis covers experiments made using flat rotating disks of 2, 3 and 5 cm diameter having controlled matt working surfaces. Rotational speeds varied from 19 000-70 000 rev/min and water feed rates were 0.121, 0.421 and 0.771 g/sec. The independent variation of Sauter mean diameter (S.m.d.) and of maximum droplet diameter with disk size, liquid flow rate and rotational speed were found and the general correlation is expressed using dimensionless groups. The extent of the dispersion is numerically expressed as a Rosin–Rammler distribution constant. Good correlation was found between both (a) S.m.d. and (b) maximum droplet diameter, and the appropriate products of dimensionless groups. The distribution constant is expressed empirically in terms of speed and flow rate, but the correlation is less satisfactory than in the case of (a) and (b). No information is given on the mode of fracture, but limitations of the analytical method are explored.

PA 63-6755

R-64. Ryley, D. J.

5808. Ryley, D. J., Experimental determination of the atomising efficiency of a high-speed spinning disk atomiser, *Brit. J. Appl. Phys.* **10**, 2, 93-97, Feb. 1959.

Electrically driven disks of 3 and 5-cm diameter were rotated at 20,000 to 60,000 rpm, and samples of aqueous spray were analyzed for flow rates of 0.12, 0.42 and 0.77 cu.cm/s. The reduction of disk speed during atomizing was determined experimentally using an electronic pulse counter, and a miniature dynamometer was devised to simulate this reduction and measure the power absorbed. Atomizing efficiencies for the electrically driven disk thus obtained are compared with the efficiency employing air drive, and also with that of a simple pressure atomizer. In all cases, efficiencies are less than 0.5 per cent. Method used was to observe the speed reduction produced by the application of the atomizing load, and then to employ a suitable brake on disk when dry to produce the same speed reduction. Difficulties are (a) the speed reduction is extremely small, and (b) the power to be absorbed by the brake is far below the capacity of orthodox instruments. A miniature rope brake was used; this is described and illustrated. Experimental results are given in sets of curves. The energy imparted to the liquid is expended on (a) creating new surface, (b) providing kinetic energy to the flung globules, and (c) deformation of globules and ligaments resulting in internal heating. Previous work, Mey 1949 and Hinze and Milborn, 1948, is discussed.

AMR 12-5808

R-65. Ryley, D. J.

1071. Ryley, D. J., An electrically-driven disk atomizer for high speeds of rotation, *J. Sci. Instrum.* **35**, 7, 237-239, July 1958.

Disk speeds ranging from 15,000-90,000 rev/min are attained by employing a variable speed d c motor/inductor alternator set and supplying the high-frequency output to a special induction motor carrying the disk. The apparatus is designed for continuous use at any speed, and several protective devices permit unattended operation. The speed is measured by employing a diametral hole in the high-speed shaft to admit a light beam intermittently to a photocell. The resulting signal is amplified and fed to a standard frequency meter. Disk diameters are 2, 3, 4 and 5 cm.

AMR 12-1071

R-66. Ryley, D. J., and M. R. Wood

1200. Ryley, D. J., and Wood, M. R., The construction and operating characteristics of a new vibrating capillary atomizer, *J. Sci. Instrum.* **40**, 6, 303-305, June 1963.

Large uniform water droplets, for collision experiments in steam, were produced by a variation of the vibrating capillary device of Dimmock. Effects of disturbance wavelength, vibration frequency, tube diameter and liquid properties are discussed but no single expression of their relationship could be derived.

Workers entering the general field of uniform droplet production should also consider Wolf's vibrating reed device [*Rev. Sci. Instrum.* **32**, p. 1124, 1961] which may have greater versatility.

AMR 17-1200

S-1. Saffman, P. G., and J. S. Turner

"On the Collisions of Drops in Turbulent Clouds," J. Fluid Mech. 1, part I, 16 (1956)

S-2. Salsas-Serra, F., and A. Planaguma

"Mechanical Atomizer for Liquids," German Patent 1,000,747, Jan. 10, 1957

S-3. Sandomirskii, M. G.

6396. Sandomirskii, M. G., Influence of the condition of the surfaces of jet orifices in the atomizers of diesel nozzles for spraying the fuel (in Russian), *Nauchn. Zap. Khar'kovsk. In-ta Mekhaniz. S. Kh.* no. 11, 57–62, 1958; *Ref. Zh. Mekh.* no. 10, 1959, Rev. 11632.

Results are given for the experimental comparative investigation of the influence of roughness of the nozzles of spray burners (made by the electro-erosional method) and of the ordinary drilled nozzle on the quality of the spraying of the fuel. The comparison of the quality of the spraying was carried out by the determination of the range and the angle of spread of the atomized fuel when the spraying was done at identical pressures into a medium of the same density ($\gamma = 17$, which corresponds to the density of the air in the motor's cylinder at the end of the compression stroke). The experiments were made with special apparatus by high-speed photography of the cone of spray in natural size and in relation to time. The experiments show that at high pressures of atomization in a rough nozzle the range of the cone of spray grows smaller, while the angle of spread gets larger by comparison with these characteristics for a drilled nozzle. Consequently it would be expedient to manufacture the jet orifices of the nozzles by the electro-erosional process.

AMR 14-6396

S-4. Sass, F.

Probleme der neuzeitlichen Ölmaschine (Modern heavy-oil engine problems). F. Sass. Forschung und Technik, Allgemeine Elektrizitäts-Gesellschaft, 1930.

Flow in nozzles; equation of efflux velocity for turbulent and for laminar flow; influence of viscosity and of velocity; production of nozzle orifices; influence of elasticity of needle valve on injection; spray penetration; intensity of spray. Survey of research at Pennsylvania State College and at NACA; devices for the measurement of spray distribution and for injection pressure.

deJ I-308

S-5. Sass, F.

Kompressorlose Dieselmaschinen. F. Sass. Julius Springer, Berlin (1929), 392 p., 328 fig.

Treatise on theory and design of solid injection oil engines; pages 41–72, with 45 fig. are devoted to discussion of spray formation, atomization, penetration, and experiments dealing with these. Pages 125–235 deal with design of fuel injection systems. Investigations of author on drop sizes by catching the drops in liquid, (glycerin), and counting the numbers in various size groups. Spray photography by spark discharge.

deJ I-308

S-6. Sauter, J.

Untersuchungen der Zerstäubung durch Spritzvergaser (Investigation of atomization in carburetors). J. Sauter (Tech. Hochsch. München). VDI-Forsch.-Heft (Germ.), No. 312 (1928), 30 p. Abstract: VDI-Z. (Germ.), Vol. 72 (1928), pp. 1572–1574. Translation of abstract: NACA Memo. No. 518 (1929), 10 p., 6 fig.

Air was drawn through a carburetor by means of an air pump (4.24 cu. ft. per sec. maximum). The intake pipe was fitted with a glass window, which could be rotated to remove the accumulated drops by wiping. Airtightness was attained by felt rings. Fineness of atomization is expressed by the "mean size" of drops, which is that diameter of which the surface area to volume ratio is the same as for the spray. This is measured by photo-electric means, by measuring the degree of dimming of a light beam passing through the spray. Various types of carburetors (Claudel-Hobson, Zenith, Pallas) were tested with pipes of different diameters, and with air venturis of 24, 26, and 28 mm. diameter, using various fuel jets. Experimental arrangement; calculation of mean drop size; charts of representative results.

deJ I-310

S-7. Sauter, J.

Beurteilung der Güte einer Zerstäubung nach ihrer Feinheit und Gleichmäßigkeit (Determining the efficiency of atomization by its fineness and uniformity). J. Sauter. VDI-Forsch.-Heft (Germ.), No. 279 (1926). Transl.: NACA Memo. No. 396 (1927), 23 p., 2 fig.

Defines 6 different mean radii of drops and shows their interrelations. Derives terms for describing the uniformity of spray and discusses their value for evaluating the mixture in the intake manifold of carburetor engines. Points out that mean radii can be determined without kno[illegible] the individual drop sizes, but uniformity cannot.

deJ I-309

S-8. Sauter, J.

Die Größenbestimmung der im Gemischnebel von Verbrennungskraftmaschinen vorhandenen Brennstoffteilchen (Determination of drop size in fuel mixture of internal combustion engines). J. Sauter. VDI-Z. (Germ.), Vol. 70 (1926), pp. 1040–1042. Transl.: NACA Memo. No. 390 (1926).

Variation of drop sizes in a given mixture, its graphical representation, and definition of "mean drop size". Reviews ten different methods used, two of which are originated by the author: (1) measuring the electrical charge transported, which is proportional to the total surface of the globules; (2) measuring the light absorption by the spray, which increases with increasing fineness of atomization. Tests are described on water atomized by a carburetor. Derivation of formulae.

deJ I-309

S-9. Savart, F.

Mémoire sur le Choc de deux Veines Liquides animés de Mouvements directement opposés (Memorandum on the impact of two liquid jets moving in direct opposition). Felix Savart. Annales de Chimie et de Physique, Vol. 55, 1834, pp. 257–310, 21 fig.

Shows experimental arrangement which consists of two parallel upright vessels fitted with interchangeable nozzles near the bottom, facing each other. The jets issuing from the nozzles and impinging against each other produce a liquid sheet of various configurations, according to the sizes of the opposing orifices, the pressures in each of the two vessels, the volume of the two vessels, and choice of other variables. The various liquid sheet configurations are shown in clear drawings.

deJ II-335

S-10. Savart, F.

Mémoire sur la Constitution des Veines Liquides Lancées par des Orifices circulaires en Mince Parois (Memorandum on the structure of liquid jets issuing from circular, thin-wall orifices). Felix Savart. Annales de Chimie et de Physique, 2 Ser., Vol. 53, 1833, pp. 337–386, 22 fig. (In German: Über die Beschaffenheit der durch kreisrunde Öffnungen aus dünner Wand strömender Flüssigkeitsstrahlen. Poggendorff's Ann. d. Physik. u. Chemie. Leipzig, Vol. 33, 1834, pp. 451–477, and 520–537, 23 fig. Also in abtsracted form, in Poggendorff's Ann. d. Physik u. Chemie, Vol. 29, 1833, pp. 353–356.)

Investigated liquid jets issuing from a thin-wall, circular orifice, from a cylindrical container, downward, horizontally, obliquely upward, and vertically upward. Illustrates and discusses the different configurations of the jets, the first unbroken smooth portion next to the orifice, then the oscillating, bulging and constricting portion and finally the breaking up of the jet into drops. Illustrates and describes the experimental setup, and the sharp-edged orifice. Studied influence on jet of acoustic vibrations and the sound produced by the impact of the discontinuous part of the jet upon the body on which it fell.

deJ II-334

S-11. Savic, P.

3612. Savic, P., Circulation and distortion of liquid drops falling through a viscous medium, *Nat. Res. Counc. Canad. mech. Engng. Rep.* MT-22, 56 pp., July 1953.

Existing theories of circulation in drops moving through a viscous medium are examined and found to be at variance with observation on water drops moving in castor oil. It is concluded that the suppression of circulation in small drops is due to a surface-active layer, the extent of which is governed by the balance between interfacial tension and the integral of viscous surface shear. The streamline picture and the relation between size of surface layer and drag are found to be in good agreement with experiments, but the critical drop radius for transition from non-circulating to circulating condition is found to be somewhat lower than predicted.

The shape of a distorted drop suspended in a gas stream is calculated and found to be in general qualitative agreement with experiments in a vertical wind tunnel. The difference in wind velocity for breakup between a steady and a suddenly applied gas stream, at least for very small drops, is ascribed to a higher rate of distortion under purely potential motion assumed to exist during a sudden blast. This assumption is shown to agree well with published experimental evidence.

The development from rest of circulation in a drop is calculated for two conditions, viz., when the internal viscosity is high and when it is low compared with the viscosity of the surrounding fluid. It is shown that the time required to attain full circulation in the first case is over four times that in the second case. A numerical example of a kerosene spray in a combustion chamber shows that circulation may be a factor liable to affect the assessment of ignition-delay times.

AMR 7-3612

S-12. Savic, P.

3771. Savic, P., Hydrodynamical and heat transfer problems of liquid spray droplets, *Nat. Res. Counc. Canad., Div. mech. Engng., Quart. Bull.* 5 pp. + 4 figs., Jan./Mar. 1953.

The dynamics of liquid droplets moving in a continuous medium was studied by means of high-speed photography in a vertical wind tunnel having a slowly diverging working section in which droplets could be kept suspended in a stable position over a period of several minutes. The shape of the drop oscillates about a symmetrical mean shape. As the droplet diameter increases, the underside of the drop flattens, then a dimple appears; finally, the drop becomes bag-shaped, breaks up, and rolls into smaller droplets. To a certain degree this phenomenon can be explained also theoretically, by equating the aerodynamic pressure to the gravity and capillary forces. It was also found that a lower air velocity is needed to break up the droplet in a suddenly applied air stream.

The circulation within the drop has an influence on the heat transfer. The circulation is greater when the drop is larger, and thus compensates to some extent for the lesser surface-to-volume ratio, as far as temperature rise, and therefore ignition delay, is concerned. This phenomenon was examined experimentally using liquid-in-liquid drops of large size, and taking pictures of the flow within the drop. However, it is admitted that circulation is probably absent in droplets of a size usual in fuel sprays, unless the temperature is high enough to reduce the surface tension below a certain critical level.

Some interesting conjectures are advanced regarding combustion, the hydrodynamic repulsion of the droplets, demulsification of emulsions. It is also surmised that colloidal techniques may be utilized to aid in the control of combustion and evaporation of sprays, and in other process phenomena.

AMR 9-3771

S-13. Schene, H.

Schene, H.
ATOMISATION PROCESSES IN PAINT SPRAYING.
1960, 9000 words.
Order from TTIS $60.00 **TT15-2208**

Trans. of Industrie-Lackier-Betrieb (West Germany) 1960, v. 28, July 207/16-Aug 243/49.

T4-574

S-14. Scheubel, F. N.

Über die Zerstäubung in Vergasern (On atomization in carburetors). F. N. Scheubel. Jbch. Wiss. Ges. Luftfahrt, Oldenburg, München and Berlin (1927), pp. 140–146. Transl.: NACA Memo. No. 644 (1931), 10 p., 8 fig., 4 p. of spray photographs.

Pictorial description of atomization phenomena in an air stream. High speed photographs of atomization of water and alcohol in carburetors. Globule sizes were determined from the photographs and compared with values derived from dimensional analysis. Correlation of mean droplet size with surface tension, density, and viscosity of fuel, and air velocity.

deJ I-312

S-15. Schlick, E.

"Electrically Charged Atomizer for Liquids," German Patent 967,496, Nov. 14, 1957

S-16. Schmarbeck, E.

"Method and Nozzle for the Compressed-Air Atomizing of Liquid Pesticides," German Patent 825,920, Dec. 27, 1951

S-17. Schmidt, J. M.

An Experimental Study of the Behavior of Liquid Streams Injected into a Low-Pressure Chamber. J. M. Schmidt. Jet Prop. Lab., Cal. Inst. Techn. Progr. Rept. No. 4–94 (1949), 16 p., 20 fig.

A stream of carbon tetrachloride of 0.140 in. diameter was injected into a transparent evacuated chamber, with the purpose of studying the behavior of liquid propellants in rockets. Time records of included spray-cone angle, and increase in chamber pressure due to vaporization, were taken as a function of vapor pressure, initial chamber pressure, pressure drop across the injection orifice, and distance from the control valve to the orifice. Results indicate that the degree of jet disintegration is primarily a function of vapor and chamber pressures. Injection pressure drop has only a secondary effect, that it influences the instantaneous chamber pressure which in turn affects the spray cone angle. Distance from control valve to orifice has no noticeable effect. Empirical equation for relation between spray-cone angle, initial chamber pressure, instantaneous chamber pressure, and vapor pressure was obtained.

deJ I-314

S-18. Schmidt, J. M.

A Preliminary Investigation of the Atomization of Liquids Injected into an Air Stream. J. M. Schmidt. Jet Prop. Lab., Cal. Inst. Techn., Progr. Rept. No. 4–101 (1949), 20 p.

One method for measuring droplet sizes utilizes a photoelectric photometer. In another method samples of the spray are caught on a magnesium-oxide covered slide. Limitations of both methods are critically evaluated.

deJ I-314

S-19. Schmidt, J. M.

Measurement of Droplet Sizes by the Diffraction Ring Method. J. M. Schmidt. Jet Prop. Lab., Cal. Inst. Techn., Progr. Rept. 3–18 (1948), 12 p., 6 fig.

Presents brief theory of the formation of diffraction rings (coronae) around drops. Describes experimental techniques used in applying this method to measurement of drop sizes in sprays. In many typical sprays drop sizes vary so much that the method is not applicable, but it can be used with sprays from hollow-cone injectors. Typical results from one such injector are given and compared with the determination of mean drop size by other methods.

deJ I-314

S-20. Schmidt, J. M.

"Application of the Photoelectric Photometer to the Study of Atomization," Calif. Inst. Tech., J.P.L., Prog. Rpt. No. 3-15, 13 pp., July 30, 1946

S-21. Schneider, J. M., and C. D. Hendricks

29607 SOURCE OF UNIFORM-SIZED LIQUID DROPLETS.
J. M. Schneider and C. D. Hendricks.
Rev. Sci. Instrum. (USA), Vol. 35, No. 10, 1349-50 (Oct. 1964).

A method useful in the production of streams of uniform-sized liquid droplets, which are uniformly spaced relative to one another, is discussed. An extension of the method which is useful for the production of single droplets of known size is also given. The method is based on the principle that a cylinder of liquid is dynamically unstable under the action of surface tension. A capillary wave is launched onto a cylinder of liquid or jet which selects a particular mode of instability. The process of the disintegration of the jet is thereby regularized to the extent that extremely uniform droplets result. The size of the droplets is controlled by the inside diameter of the capillary tube through which the liquid flows, and therefore, the size can be varied over wide limits. By charging individual droplets and using electrostatic means to deflect them out of the stream, individual droplets can be isolated.

PA 67-29607

S-22. Schneider, J. M., N. R. Lindblad, and C. D. Hendricks

"An Apparatus to Study the Collision and Coalescence of Liquid Aerosols." Paper presented at the 39th National Colloid Symposium of the ACS Division of Colloid and Surface Chemistry; Clarkson College of Technology, Potsdam, N.Y., June 21, 1965

S-23. Schreiner, K.

3828. Schreiner, K., Design of spray nozzles (in German), *VFDB-Zeitschrift* **6**, 3, 128-133 + 13 figs. + 2 ref., Aug. 1957.

Survey of influencing factors for atomizing nozzles, such as jet diameter, velocity, turbulence, surface tension, compressibility, and direction of flow. Each of these factors are critically examined from the point of view of improving the atomization, and as to their incorporation into the design of multipurpose nozzles. Drawings are shown of a multiorifice nozzle, an air-atomizing nozzle, annular slit nozzle, impinging nozzle, swirl nozzle, and several variable nozzles which can be switched over from one type of jet to another.

AMR 10-3828

S-24. Schultze, K.

4997 THE BEHAVIOUR OF DIFFERENT LIQUIDS DURING ELECTROSTATIC ATOMIZATION. K.Schultze.
Z. angew. Phys. (Germany), Vol. 13, No. 1, 11-16 (Jan., 1961).
In German.

The liquids investigated were classified according to their electrical conductivity, ranging from highly insulating transformer oil to aqueous salt solutions. The liquids were allowed to issue from fine glass or metal jets, a voltage of up to 12 kV being applied with respect to a plane 15 mm below this orifice. The nature of the atomization was observed and the quantity of liquid dispersed per unit time measured. Optimum results were obtained with liquids in the conductivity range 2×10^{-8} to 6×10^{-8} ohm^{-1} cm^{-1}. The effects of hydrostatic pressure, orifice diameter and viscosity of the liquid were also studied.

PA 65-4997

S-25. Schwarz, N., and C. Bezemer

A New Equation for the Size Distribution of Emulsion Particles. N. Schwarz and C. Bezemer (Koninklijke Shell Laboratorium, Amsterdam, Holland). Kolloid-Zeitschrift, Vol. 146, No. 1–3 (1956). Part I. Derivation and application to experimental data, pp. 139–145, 4 fig., 17 ref. Part II. Validity of the equation, pp. 145–151, 3 fig., 8 ref., discussion.

Previous attempts are described for formulating mathematical functions for histograms of size distribution of dispersed particles, as emulsions, sprays, etc. Authors propose an exponential function with two parameters: a characteristic diameter and the largest droplet diameter, both of which can be derived from a linear plot of experimental data. Application to several published experimental data yields good agreement between theory and experiment for mechanically prepared emulsions. Validity of equation is examined applying the criteria of goodness of fit and agreement of average diameters. Comparison with two widely used distribution functions with two parameters, viz. the log-probability and the Rosin-Rammler function, shows that the new function has closer fit with the experimental size-distribution data for emulsion particles. It is pointed out that the Rosin-Rammler function has been developed primarily for comminuted solids; furthermore, that all proposed distribution functions fail in the description of histograms having two maxima, which occur when two simple dispersions are present, produced by two different physical mechanisms, e. g., by atomization and by condensation in the case of liquid sprays.

deJ I-315

S-26. Schweitzer, P. H.

Mechanism of Disintegration of Liquid Jets. P. H. Schweitzer. Jl. Appl. Phys., Vol. 8 (1937), pp. 513–521, 10 fig., 17 ref.

Theories and researches of Rayleigh, Castleman, Triebnigg, Kuehn, Scheubel, Haenlein, Lee; hydraulic turbulence in orifices, and its effect on atomization. Dispersion of various oils at varying oil and air pressure. Breakup distance and cone angle of spray at various pressures and viscosities.

deJ I-316

S-27. Seebaugh, W. R., and D. H. Lee

N62-23558 Princeton U., N J Guggenheim Laboratories for the Aerospace Propulsion Sciences
AN OPTICAL METHOD FOR OBSERVING BREAKUP AND VAPORIZATION OF LIQUID JETS
W R Seebaugh and D. H Lee June 1963 101 p 32 refs
(NASA Grant NsG-99-60)
(NASA CR-52081. Aeronautical Eng Rept 647) OTS $9.10 ph. $3.23 mf

An optical method for observing and analyzing the breakup and vaporization of liquid jets was developed. Schlieren and shadow photographs are presented to illustrate the effects of varying the relative knife-edge cutoff, focusing, film position, and exposure duration. Shadow photographs of fully developed, turbulent flow jets employing several liquids including water, ethyl alcohol, dichlorofluoromethane (Freon-21), liquid oxygen and dichlorodifluoromethane (Freon-12) are presented and analyzed. Application of the data obtained to combustion instability research is discussed.

N62-23558, 24-27

S-28. Seidl, F.

"Observations on Oil Fountains Produced by Ultrasonics," Acustica 2, No. 1, 45-7 (1952)

S-29. Semerchan, A. A., et al.

Semerchan, A. A., Vereshchagin, L. F., and others.
HYDRAULIC PLANT FOR GENERATION OF LIQUID STREAMS AT SUPERSONIC SPEEDS
(Gidravlicheskaya Ustanovka dlya Polucheniya Struy Zhidkosti Sverkhzukovoy Skorosti). 10 Oct 60 [10]p.
(11 figs. omitted) 3 refs. MCL-138/1.
Order from LC or SLA mi$1.80, ph$1.80 61-19328

Rough draft trans. of *Pribory i Tekhnika Eksperimenta (USSR) 1959, no. 1, p. 121-125.

T5-573

S-30. Semerchan, A. A., et al.

Semerchan, A. A., Vereshchagin, L. F., and others.
SUPERSONIC LIQUID JETS AND EXPERIMENTAL HYDRAULIC PLANT FOR 30,000 LB./SQ. IN. PRESSURE. [1960] [5]p. 3 refs. M857.
Order from LC or SLA mi$1.80, ph$1.80 60-13663

Trans. of *Pribory i Tekhnika Eksperimenta (USSR) 1959, no. 7, p. 121-125.

T4-174

S-31. Semerchan, A. A., et al.

539*. Distribution of Momentum in a Continuous Fluid Jet at a Supersonic Velocity. Investigation of a continuous horizontal fluid jet at subsonic and supersonic (from 300 to 540 meters per second) velocity. Diagram of equipment used for the experiments. Experimental results. Relationship between viscosity of flowing out fluid and the angle of conicity of the jet. An increase of viscosity decreases angle of conicity. (*In Russian.*) Raspredelenie kolichestva dvizheniia v nepreryvnoi zhidkostnoi strue sverkhzvukovoi skorosti. *A. A. Semerchan, et al. Zhurnal Tekhnicheskoi Fiziki*, v. 28, no. 9, Sept. 1958, p. 2062-2071 + 1 plate.

BMI 8-539

S-32. Shafer, M. R., and H. L. Bovey

3375. Shafer, M. R., and Bovey, H. L., Applications of dimensional analysis to spray-nozzle performance data, *J. Res. nat. Bur. Stands.* 52, 3, 141-147, Mar. 1954.

Applications of dimensional analysis to performance of continuous fuel spray nozzles of the centrifugal type. Equations show the relations between nozzle capacity, nozzle dimensions, mean drop diameter, spray angle, fuel pressure, and the density, viscosity, and surface tension of fuel. Using experimental data available at the National Bureau of Standards and in the literature, good correlation has been found as to nozzle capacity and a fair correlation as to mean drop diameter and spray angle. The theoretical investigation is based on the application of Buckingham's pi- theorem to the flow rates of the simplex and duplex types of nozzle and to the mean drop size and angle of the spray. Author states that the curves given apply only to the particular nozzles investigated and have no general validity. The method, however, promises economy in analyzing, correlating, and interpreting experimental data from a limited number of experiments, and predicting differences in performance due to the use of liquids having different physical properties.

AMR 7-3375

S-33. Shapiro, A. H., and A. J. Erickson

3421. Shapiro, A. H., and Erickson, A. J., On the changing size spectrum of particle clouds undergoing evaporation, combustion, or acceleration, 1956 *Heat Transfer and Fluid Mechanics Institute*, Stanford, Cal., Prepr. no. 8, 30 pp.

Many industrial processes require that a cloud of solid particles or liquid droplets interact with the gaseous (or, sometimes, liquid) phase in which they are dispersed. In certain of these processes there is a spectrum of particle sizes, and moreover, the particles change in size by reason of interaction. Examples include: (a) evaporation of a cloud of liquid droplets; (b) growth of a liquid cloud by condensation; (c) combustion of either solid fuel particles or liquid fuel droplets. Normally the rate of growth (in an algebraic sense) of each particle will depend, among other things, on the diameter of the particle itself. Under such conditions the shape of the particle spectrum will change as time proceeds, and this naturally introduces difficulty into the analysis of the problem. Even when there is no change in particle size, the spectral distribution of sizes may change; e.g., if the cloud is accelerated, different sizes of particles will accelerate at different rates, and the differences in particle speeds will alter the relative concentrations per unit volume of the several particle sizes.

A theoretical treatment is given showing how the size distribution of a cloud of particles changes as a result of evaporation, combustion, or acceleration. The general differential equation governing the concentration of particles as a function of size, position, and time is formulated for one-dimensional duct-type flows. Solutions to the differential equation are then obtained for a number of special problems of interest to evaporation and combustion.

If the process depends mainly on molecular transfers (i.e., at very low Reynolds numbers), the equivalent mean diameter for evaporation or combustion of drops is found to be approximately constant with time. This suggests that the conventional model of a constant number of uniform drops of varying size be replaced by a new model having a varying number of uniform drops of constant size. The new model predicts a lower rate of evaporation or combustion than the conventional model.

AMR 9-3421

S-34. Shaw, W. C.

"An Efficient Sprayer for Application of Chemical Sprays to Experimental Field Plots." Warren C. Shaw (Ohio State Univ., Columbus). J. Agron. 43, 158-60 (1950)

S-35. Shcherbakov, L. M., and A. S. Bolotin

"Relation of Surface Tension to the Radius of the Drop." L. M. Shcherbakov and A. S. Bolotin. Ucherye Zapiski Kishinev. Univ. 11, 153-6 (1954); Referat. Zhur., Fiz. 1955, Abstr. No. 21642.

CA 52-19394b

S-36. Shimosaka, M.

"Theoretical Study of the Forms of Jets from Nozzles." Trans. JSME 6, S-11 to S-13 (1940)

S-37. Sidorov, E. A.

529. Sidorov, E. A., Calculation of laminar flow of drop-forming liquids through tubes, with inclusion of nonisothermal effects (in Russian), *Soviet Phys.-Tech. Phys.* **2**, 2, 292-296, Feb. 1957. [Translation of *Zh. tekh. Fiz., Akad. Nauk SSSR* **27**, 2, 327-330, by Amer. Inst. Phys., Inc., New York, N. Y.]

Variation of physical properties of liquids with temperature is one of the most important sources of disagreement between theoretical solutions and experimental data on the distributions of velocity and temperature in the laminar flow of liquids through tubes. Author states the approximate equations of motion and of heat transfer in the boundary layer in a cylindrical tube. Based on these he derives mathematically the temperature and velocity fields in laminar flow of drop-forming liquids through tubes, including the effect of viscosity variation with temperature. Previous research is discussed.

AMR 12-529

S-38. Siemes, W., and J. F. Kaufmann

2188. Siemes, W., and Kaufmann, J. F., Drop formation in liquids in nozzles at high rates of flow (in German), *Chem.-Ing.-Tech.* **29**, 32-38, 1957.

Drop formation at round, smooth-edged, vertical orifices, at medium and high flow rate is investigated. Size of drops, and characteristic quantities derived from it, were determined as functions of rate of flow, orifice radius, and liquid characteristics of the continuous and the dispersed phase, in order to clarify phenomena in solvent-extraction and in liquid-liquid reactions in chemical processes. Five orifices, with diameters of 1,2,3,4 and 6 mm were used, the flow velocity was varied from 20 to 200cm/sec; the continuous-phase liquid was water and sugar solution, and the disperse phase liquids were gasoline, benzol, turpentine, and paraffin of various densities, surface tensions, and viscosities. Flash photography technique was used, and the photos were evaluated for drop-size distribution; the results are represented in drop-size spectrum curves, and in specific surface (total surface of drops divided by total volume) curves as functions of the various liquid properties.

AMR 11-2188

S-39. Siestrunk, R.

Sur les Regimes du Resolution des Jets Liquides sous l'Influence d'un Soufflage Axial (On the breaking-up process of liquid jets under the influence of an axial air stream). R. Siestrunk. Compt. Rend. (France), Vol. 215 (1942), pp. 404–406.

Explains the break-up of jet as due to amplification of oscillations by the drag. Drops are broken up by pressure due to drag, and centrifugal pressure due to rotation caused by collision with eddies of the gas stream. Develops formulas based on these assumptions.

deJ I-322

S-40. Sitkei, G.

A Keverékképzés és Égés Lefolyása Diesel-Motorokban (Mixture formation and combustion in Diesel engines). George Sitkei (Hungarian Polyt. Univ., Budapest, Hungary). Publ. Academy Publishing Co., Budapest, Hungary, 1960, 206 p., 128 fig., 7 tabl., 66 ref.

A detailed, mainly theoretical and mathematical treatise on subject, based partly on previous research work in several countries, and partly also by author and coworkers; these are listed in the references, about half of which refers to Soviet research in this field. Some experimental research is also included, mainly in the form of graphs and tables; a few design drawings illustrate the concepts and principles. Headings: I. The injection process (general considerations, calculation of velocity and pressure phenomena with open and with closed nozzle, work of injection, influence of design parameters on the injection characteristics; effect of injection pipe; application of similitude). II. Theory of atomization (causes and forms of jet breakup, external and internal forces, dynamics of drops, penetration, cone angle, distribution of fuel in the spray). III. Evaporation (heat transmission to droplets, characteristics of evaporation and diffusion and influence of air stream, evaporation of diesel fuel and its effect on the working cycle). IV. Diesel combustion (general principles, self-ignition phenomena in hydrocarbon-air mixtures, effect of physical and chemical data of fuel on the process of ignition and combustion, stages in combustion, ignition lag, propagation of combustion, indicator diagram, and dynamics of cycle). V. Process of mixture formation in various combustion chambers (general problems of mixture formation, combustion chambers for direct injection, swirl chambers, precombustion chambers, calculation of flow phenomena, energy relations and subdivision of energy requirements during mixture formation, heat-balance of diesel engines).

deJ II-342

S-41. Sitkei, G.

6107. Sitkei, G., On the theory of jet atomization (in German), *Acta Techn., Acad. Sci. Hungaricae, Budapest* **25,** 1/2, 87-117, 1959.

In the present study the external and internal forces acting upon the liquid jet have been treated. It has been shown that the decomposition into drops of the jet is caused mainly by the intensive low-frequency turbulent pulsation acting as an internal force on the one hand, and the incidental dynamic power, arising on the front surface of the moving drops, as an external force on the other hand. By taking the above theory as a basis, relations of quantitative character have been deduced for the mean drop diameters.

The conditions of jet movement are discussed and, as a result, the author has succeeded in finding a characteristic function describing correctly the movement conditions of the jet as a function of various parameters. Finally, a method for an approximate determination of the fuel distribution is published.

AMR 13-6107

S-42. Skalamera, J. J.

"Automatic Analysis of Particle-Size Distribution Data," Univ. Delaware, Chem. Eng. Dept., M. S. Thesis, 1953

S-43. Sleicher, C. A., et al.

10631 **FLUID DYNAMICS. C.A.Sleicher, Jr., R. ? Stern, L.E.Scriven and A.K.Oppenheim.**
Industr. engng. Chem., Vol. 52, No. 4, 347-58 (April, 1960).

Review of recent literature (books, periodicals, conference proceedings and reports) on the following: equations of motion and stability; turbulence; vortex flow and rotation; jets and wakes; flow near solid surfaces; multiphase and free-boundary flow; gas dynamics; gas wave dynamics; dynamics of reactive fluids; dynamics of conducting fluids. The bibliography (arranged under the foregoing headings) comprises 252 items.

PA 63-10631

S-44. Sliepcevitch, C. M., et al.

"Operating Characteristics of a Vibrating-Type Atomizing Nozzle." C. M. Sliepcevitch, J. A. Consiglio, and Fred Kurata (Univ. of Michigan, Ann Arbor). Ind. Eng. Chem. 42, 2353-8 (1950).

CA 45-1390b

S-45. Smith, D. A.

"Spray-Drying Equipment." Factors in design and operation. D. A. Smith. Chem. Eng. Progress 45, 703-7 (1949).

CA 44-880h

S-46. Smith, S. W. J., and H. Moss

Experiments with Mercury Jets. S. W. J. Smith and H. Moss. Proc. Roy. Soc. Arts (Engl.), Vol. 93 (1917), pp. 373–393.

Experiments on break-up distance of low-speed jets.

deJ I-326

S-47. Söhngen, E., and U. Grigull

170. Söhngen, E., and Grigull, U., Spray angle of fuel-injection nozzles of swirl type under steady injection conditions (in German), *Forsch. Geb. Ing.-Wes.* (*B*) 17, 3, 77-82, 1951.

Experimental results are presented of tests of 18 different fuel-injection nozzles of the swirl type. The nozzles were made up of different combinations of six housings and three swirl-producing inserts. The nozzles differed systematically as to length and diameter of the discharge orifice, diameter of the radial drillings in the swirl inserts, and depth of the swirl chamber. Measurements were made of flow angle at various combinations of fuel flow and pressure for all the nozzle combinations. The measurements are plotted against several characteristic design parameters, and are compared with theoretical calculations based on ideal flow in frictionless nozzles.

AMR 6-170

S-48. Sokolov, V. N., and A. S. Reshanov

Sokolov, V. N. and Reshanov, A. S.
THE EFFECT OF TIME ON SUBDIVISION OF DROPLETS IN A STREAM MADE TURBULENT BY A SPARGING GAS. [1960] 8p.
Order from ATS $9.00 ATS-85M42R

Trans. of *Zhur[nal] Priklad[noy] Khim[ii] (USSR) 1960, v. 33, no. 5, p. 1068-1075.

T4-576

S-49. Sollner, K.

"The Mechanism of the Formation of Fogs by Ultrasonic Waves," Trans. Faraday Soc. 32, 1532 (1936)

S-50. Somin, V. I., and V. A. Pis'mennyi

"Atomizer for Introducing and Maintaining Low Concentrations of Volatile Compounds in Air." V. I. Somin and V. A. Pis'mennyi. Farmakol. i Toksikol. 24, 497-9 (1961).

CA 56-1699f

S-51. Somogyi, D., and C. E. Feiler

Mixture Ratio Distribution in the Drops of Spray Produced by Impinging Liquid Streams. Dezső Somogyi and Charles E. Feiler (Lewis Res. Center, NASA, Cleveland, Ohio). Amer. Rocket Soc. Jl., Vol. 30, No. 2, Febr. 1960, pp. 185-187, 6 fig., 5 ref.

Rocket combustion is importantly influenced by the thoroughness of mixing of the propellants. Liquid-phase reactions of hypergolic liquid propellants depend on intensity of mixing. All injectors ultimately produce droplets of propellants; therefore it is desirable to determine the degree of mixing of the individual drops. Determined the mixture ratio of individual drops in the spray of three types of injector, using colorimetry. Illustrates and describes the instrumentation comprising a sampling device and a micro-densitometer. Determined, for each injector, the distribution and the mixture ratio vs. the number of drops, and the mixture ratio vs. spatial location; results are represented in charts. The three injectors were, in order of decreasing efficiency: the triplet, the impinging-jet, and the swirl-cup. Mixture ratio varied appreciably for a given injector, as well as among different injectors.

deJ II-345

S-52. Sorokin, V. I.

4786. ON THE EFFECT OF FORMATION OF A FOUNTAIN OF DROPS FROM THE SURFACE OF A VERTICALLY OSCILLATING LIQUID. V.I.Sorokin.
Akust. Zh., Vol. 3, No. 3, 262-71 (1957). In Russian.
A fountain of drops is shown to come about with excitation of surface-tension—gravitational standing waves at the free liquid surface. The calculated value of the excitation threshold of the waves is confirmed experimentally.

PA 61-4786

S-53. Southern Research Institute

"Factors Determining the Particle Size of Aerosols Generated by Hot-Gas Atomization," Report No. 13, Contract No. DA 18-108 CML 6423, AD 227 078, Sept. 30, 1959.

S-54. Squire, H. B.

6523. Investigation of the instability of a moving liquid film. H. B. Squire. *Brit. J. appl. Phys.*, 4, 167-9 (*June*, 1953).
The stability of a thin layer of liquid moving in still air is studied theoretically with the object of throwing light on the break-up of films during atomization. It is found that instability occurs if $W = T/\rho_2 U^2 h < 1$ and that the wavelength for maximum growth factor, for $W < 1$, is $\lambda = (4\pi T/\rho_2 U^2)$ where ρ_1 is the liquid density, ρ_2 is the air density, U is the film velocity, $2h$ is the film thickness and T is the surface tension of the liquid. Comparison with experimental data shows fair agreement with the observed wavelengths.

PA 56-6523

S-55. Squire, H. B.

"Investigation of the Instability of a Moving Liquid Film." Combustion and Fuels Sub-Committee Aeronautical Research Council, CF 213, Jan. 25, 1952, 10 p., paper No. N 26889.

S-56. Srinivas, V., V. S. Rao, and M. N. Rao

2569. Srinivas, V., Rao, V. S., and Rao, M. N., Disk atomization, *J. sci. indust. Res., India* **15A**, 1, 29-33, Jan. 1956.

In the spinning disk atomizer, the liquid is fed at the center of a rotating disk which accelerates the liquid centrifugally to high velocity and discharges it at the periphery of the disk in the form of spray. Numerous patterns of the disks, each giving a different performance, have been evolved. Performance characteristics are weight distribution, drop-size distribution (compact and dense, or widespread spray) and power requirements. The power input is mostly used up by the drive of the disk, and, to a less extent, to overcome the friction of flow across the disk and the kinetic energy imparted to the drops; the power spent in creating the extra surface is only a very small portion of the energy. Marshall and Seltzer's equations for the viscous flow across the revolving disk is explained.

An attempt is made to determine experimentally the actual velocity of the drops leaving the disk. Brass disks, about 2-in. diam, were driven at speeds from 1000 to 10,000 rpm with the disk mounted vertically on a horizontal spindle, photographs were taken of drops traveling vertically upwards, at the upper region of their trajectory where their velocity was already reduced by gravitational force and by air resistance; the streak width of the drop image was measured with a traveling microscope. Results are given in a sample calculation and in tabulated representation.

Developing a realistic theory is complicated by the air-aspiring action of the disk, frictional drag between the disk surface and the air, and transfer of momentum to the air from the spray. Work is in progress on effect of feed rate, disk design, and velocity on the size of the drops and their leaving velocity.

AMR 9-2569

S-57. Stamm, K.

Stamm, K., "Aerosol Production from Molten Solid Bodies with the Help of Ultrasonics" (in German), Forschungsber. des Lanes Nordrhein-Westfalen no. 933, 24 pp., 1960.

S-58. Stange, K.

712. Stange, K., Size distribution laws in disintegration processes (in German), *Ing.-Arch.* 21, 5/6, 368-380, 1953.

Particle size distribution is an important property of solid powders and of liquid sprays. The empirical equations which have been developed usually correlate some size distribution data but are unsuitable for other data. Theoretical or semi-theoretical derivations of these equations could lead to a better choice of a correlating equation for a given case, or, in some cases, to a determination of the particular distribution process involved. This paper gives such a derivation for two simple model processes, operating on a number of initially uniform particles: (1) a p-fold repetition of n simple breakup into two parts; (2) a single breakup into k parts. In both cases, the individual breakup process is assumed to occur statistically. The first process leads to the logarithmic-normal distribution and the second to a distribution which approximates the Rosin-Rammler equation over the usual range of size distribution data.

Reviewer believes paper is an interesting and well-thought-out contribution to the problem, but is not completely novel. Derivations of the log-normal equation have been given by B. Epstein [*Indust. Engng. Chem.* 40, 2289, 1948], F. Kottler [AMR 4, Rev. 1878], and R. A. Mugele and H. D. Evans [*Indust. Engng. Chem.* 43, p. 1317, June 1951]. Kottler has recently extended his work to show how two similar processes of different rates can lead to a complex combination of two log-normal distributions [*J. phys. Chem.* 56, p. 412, 1952]. Another approach to a generalized Rosin-Rammler equation has been recently given by Weibull [*J. appl. Mech.* 18, p. 293, Sept. 1951].

AMR 8-712

S-59. Stehling, K. R.

"Injector Spray and Hydraulic Factors in Rocket Motor Analysis," J. Am. Rocket Soc. 22, 132 (May-June 1952)

S-60. Stehling, K. R. and R. W. Foster

814. Stehling, K. R., and Foster, R. W., Liquid jet atomization by a sonic nitrogen stream, *Jet Propulsion* **24, 6, 384-385, Nov.-Dec. 1954.**

As part of a research project on a rocket thrust chamber, a study was undertaken on the atomization and penetration of liquid (water) streams injected at various velocities and angles into a sonic gas stream.

AMR 9-814

S-61. Stepanov, V. F.

"Apparatus for Atomizing Liquids." V. F. Stepanov. U.S.S.R. 69, 797, Dec. 31, 1947.

S-62. Stoker, R. L.

A method of determining the size of droplets dispersed in a gas. Stoker, R. L. *J. Appl. Phys.*, 17, 243-5 (*April*, 1946).—The method makes use of the fact that if droplets strike a suitably coated surface without wetting the surface, a track of the contact area is formed. A criterion is derived and experimentally evaluated for relating the droplet diameter and the track diameter. An apparatus for utilizing this method is briefly described.

PA 49-1526

S-63. Straubel, H.

Straubel, Harold.
THE ELECTROSTATIC ATOMIZATION OF LIQUIDS. Preliminary Report. [1962] 6p. (7 figs. omitted) 2 refs.
Order from SLA $1.10 62-16631

Trans. of Zeitschrift für Angewandte Physik (West Germany) 1954, v. 6, no. 6, p. 264-267.

DESCRIPTORS: *Electrostatics, *Atomization, Liquids, *Organic compounds, Electron microscopy

The properties of various organic liquids are discussed with regard to the best atomization. It is shown as to how the charged floating particles are applied to model experiments on the electron motion, either in the Braun's tube or in the electron microscope.

T8-662

S-64. Straubel, H.

8262. Electrostatic atomization of liquids. H. Straubel. *Naturwissenschaften*, **40**, *No.* 12, 337 (1953) *In German.*

A brief note describing experiments in which a liquid which would otherwise just not emerge from a small nozzle forms a fine spray on the application of a potential of 10-20 kV.

PA 56-8262

S-65. Straus, R.

"The Mechanics of Formation of Liquid Droplets in Sprays," Ph.D Thesis, London University, 1949

S-66. Strazhevsky, L.

Investigation of Atomization of Liquid Fuel. L. Strazhevsky. Jl. Techn. Phys. (USSR), Vol. 4, No. 11–12 (1937), p. 978.

Shows that a multi-disperse spray evaporates slower than mono-disperse spray although both have the same total drop volume and the same surface area. Suggests use of carbon black for catching droplets so that impingement leaves pits proportional to drop size.

deJ I-333

S-67. Stubbs, H. E., and J. L. York

"Photographic Analysis of Sprays." Presented Ann. Meeting, ASME, Atlantic City, N.J., Nov. 25-30, 1951.

S-68. Szlackin, J. A.

"Notes on Atomization of a Liquid at Low Injection Pressures," Bell Aircraft Corp., METEOR Rpt. No. BAC-5, 11 pp., June 20, 1947

T-1. Talakvadze, V. V.

4071. Talakvadze, V. V., The theory and design of centrifugal nozzle (in Russian), *Teploenergetika* no. 2, 45–49, 1961.

As noticed by the editor this paper is published for discussion. The theory reported is based on assumptions which are similar to those of G. I. Taylor and concerns both nonviscous and viscous liquids. Numerical results are summarized by means of two graphs and one table in terms of nondimensional parameters and the successive steps of computation for nozzles with losses are presented. Author believes that his method gives values of the discharge coefficient and the angle of aperture of the spray which agree within 10% with the observed values.

AMR 15-4071

T-2. Tamura, K. and T. Takeda

"Production of Copper Powder by Atomization." Kiyoshi Tamura and Tooru Takeda. Trans. Natl. Res. Inst. Metals (Tokyo) 5(5), 252-6(1963).

CA 60-10308g

T-3. Tanasawa, Y. and H. Hiroyasu

4291. Tanasawa, Y., and Hiroyasu, H., On a drop size analyzer for liquid sprays by sedimentation, *Technol. Rep., Tohoku Univ.* **27**, 1, 67–89, 1962.

Droplet-size distribution in the fuel spray injected into a diesel engine has an important influence on the characteristics of the ensuing combustion, hence on the performance of the engine. One of the earliest objectives of basic diesel research has been the determination of droplet-size distribution, and in the course of years numerous schemes have been proposed and also realized for this purpose. The problem is a difficult one, because the conditions in the testing arrangement can only approximate but not fully reproduce the conditions in the engine itself.

The present paper describes a recent attempt to construct an apparatus for this purpose, which contains numerous refinements, compared with earlier devices. It is based on the sedimentation principle which has been successfully used in analogous researches on solid particles suspended in liquids, such as clays and slurries. The essential part of the apparatus is a large (6 meter high, 80 cm diameter) sedimentation tower, at the top of which the spray is injected, and at the bottom of which the droplets accumulate on the pan of a sensitive recording balance. Larger droplets fall at greater velocity than do smaller ones; the record of the balance gives the weight-versus-time curve. In order to obtain the weight-versus-diameter relationship, the device must be calibrated by the molten-wax method, yielding the relation between falling time and drop diameter. From the weight-versus-diameter relation the median diameter and the drop-size distribution can be determined.

The apparatus embodies numerous carefully thought out refinements and auxiliary equipment such as: the cut-off rotating hopper for limiting the duration of spraying to a predetermined time or to predetermined number of injections; thermostatic device comprising electric heaters, fan, and temperature regulator; photographically recording sensitive balance, provided with a chopper disk for the light beam for giving the time scale; flash lamp to mark the start of the injection; damping of the balance beam; and some others. Size distribution curves for several types of diesel nozzles are shown.

The paper discusses also the mathematical representation for the size-distribution function (Chi-square function) and gives the parameters for some of the distribution curves. The apparatus described operates at atmospheric pressure, but a modification using ambient air at higher than atmospheric density is envisaged. The paper is a noteworthy contribution to diesel engine injection research.

AMR 16-4291

T-4. Tanasawa, Y. and K. Kobayasi

531. Tanasawa, Y., and Kobayasi, K., A study of swirl atomizer, *Technol. Rep. Tohoku Univ.* **20**, 1, 27–59, 1955.

Report on researches extending from 1940 to 1952 on the basic principles of atomization by a swirl nozzle compares the experimental values of flow and atomization with the theoretical values. Conditions for optimal dimensions of simplex, duplex, variable-slot, and spill-control nozzles have been considered. Theory of potential flow and of viscous swirl are analyzed in detail. Modes of atomization are investigated experimentally, as dependent on (1) the form of atomizer, (2) dimensions of atomizer, (3) pressure at atomizer entry, (4) physical properties of liquid, and (5) physical properties of surrounding medium. Experimental apparatus is described, large number of spray photographs shown. Comparison is made between potential theory and actual performance, with effect of Reynolds number. Effect of inlet pressure, surface tension, length-to-diameter ratio, and of kinematic viscosity, on the size of drops is shown in charts. A numerical design example of optimum swirl atomizer is worked out. A nondimensional empirical formula is given for the surface-volume mean drop diameter and the size-distribution function.

AMR 12-531

T-5. Tanasawa, Y.; T. Kurabayasi and Y. Saito

1074. Tanasawa, Y., Kurabayasi, T., and Saito, Y., On the generation of uniform drops with rotating nozzles, *Trans. Jap. Soc. Mech. Engrs.* **22**, 116, 279–284, 1956.

This work is a continuation to Tanasawa and Toyoda (1955), to which the authors refer. Authors found that drops falling from the end of a small diameter tube were not accompanied by satellite droplets, therefore they attempted to produce a stream of uniform drops by means of rotating nozzles, and checked the results with theoretical considerations. Their main findings: (1) A parameter can be formed from the tube diameter, specific gravity and surface tension of the liquid; if this is below a certain value, uniform drops can be produced; (2) a formula is given for the maximum drop diameter at low flow values; (3) the drop diameter decreases with decreasing flow rate to its minimum value until a critical range is reached where the mode of flow changes from dripping to smooth laminar flow. This is a report of a phase of the extensive spray investigations carried on by the authors at Tohoku University.

AMR 12-1074

T-6. Tanasawa, Y., S. Sasaki and N. Nagai

535. Tanasawa, Y., Sasaki, S., and Nagai, N., A study of impingement nozzles for diesel engines, *Technol. Rep. Tohoku Univ.* 22, 2, 153-172, 1958.

The impingement nozzle has good atomizing characteristics, and can give various shapes of spray. Effects of various forms and dimensions of impingement nozzles are examined systematically. Nozzles with oblique impingment angles are tested and a design is proposed for an automatic, multi-hole, oblique-impingement nozzle for diesel engine use. Another design, with a single orifice and an impingement target plate fitted into the engine piston, is also shown. The atomization characteristics of these two new types of nozzles, and the drop-size vs. impingement velocities have been determined. A large number of photos showing the breakup of the liquid sheet into drops under various conditions are included. The investigation was carried out with the aid of the Toyota Motor Car Company.

AMR 12-535

T-7. Tanasawa, Y, S. Sasaki, and N. Nagai

533. Tanasawa, Y., Sasaki, S., and Nagai, N., The atomization of liquids by means of flat impingement, *Technol. Rep. Tohoku Univ.* 22, 1, 73-95, 1957.

Experimental study on atomization characteristics of flat, 180-deg impingement nozzles of various types. It has been found that the atomization occurs by film formation. On the basis of results a new type of impingement nozzle with flat spray and controlled flow rate is proposed for the open-chamber diesel engine. Experimental setup is illustrated and described; flow rate characteristics and discharge coefficients are determined. Flash photos of sprays with liquids of various viscosities are shown. Drop-size distribution mean drop size, and penetration of sprays are shown in charts. Drawing of a proposed impingement nozzle is given.

AMR 12-533

T-8. Tanasawa, Y. and T. Tesima

"Theory of Combustion of Liquid Fuel Spray."
Yasushi Tanasawa and Tuneo Tesima (Tohoku Univ., Sendai). Bull. JSME 1, No. 1, 36-41 (1958).

CA 52-13225e

T-9. Tanasawa, Y. and S. Toyoda

537. Tanasawa, Y., and Toyoda, S., On the atomizing characteristics of injectors for diesel engines *Technol. Rep. Tohoku Univ.* 21, 1, 117-145, 1956.

Characteristics of fuel spray having influence on the combustion in diesel engines are: (1) surface-volume mean diameter of drops, (2) distribution of drop size in spray, (3) dispersion of sprayed drops, (4) degree of distribution, (5) penetration, (6) rate of injection, (7) discharge coefficient of nozzle. Items (1) and (2), termed atomizing characteristics, have been investigated by authors by means of a very-short-time (10^{-7} sec) spark illumination, and by actual measurement of drops by the immersion liquid and by the molten-wax methods. Spark circuit ("Marx's circuit") and photographic arrangement are illustrated and described, and methods of measuring the injection pressure, timing, and needle lift explained. Photos of wax drops are shown, their separation into size groups explained. Characteristics of pintle and throttle nozzles are explained and illustrated. Impingement nozzle and swirl nozzle are shown, with new proposed modifications. Pressure diagrams of an actual diesel engine with a Sauter-type piston head with various types of nozzle are shown and compared.

AMR 12-537

T-10. Tanasawa, Y. and S. Toyoda

530. Tanasawa, Y., and Toyoda, S., On the atomization of liquid jet issuing from a cylindrical nozzle, *Technol. Rep. Tohoku Univ.* 19, 2, 135-156, 1955.

The behavior of a liquid jet was investigated with the aid of very-short-duration spark illumination, at increasing pressures, resulting first in dripping, then a lengthening stream breaking into drops at the end, roughening of the stream surface and stripping of liquid filaments from it, finally the stream breaking up into droplets forming a spray. Each of these phases is investigated theoretically also, and the results are represented in charts. Effect of injection pressure on mean drop sizes is shown. A dimensionless number termed "Jet Number" is introduced as a characteristic quantity for the mode of atomization. This paper summarizes the investigations of the authors since 1936, the various previous reports on which are listed in the references.

AMR 12-530

T-11. Tate, R. W.

"Sprays and Spraying for Process Use"
Part I - Chem. Eng. 72, 157-62 (July 19, 1965)
Part II - Chem. Eng. 72, 111-16 (Aug. 2, 1965)

T-12. Tate, R. W.

3678. Tate, R. W., Immersion sampling of spray droplets, *AIChE J.* 7, 4, 574-577, Dec. 1961.

Droplet size is an important influencing factor in most spraying processes, such as oil burning, combustion of turbojet and rocket fuels, spray drying, cooling and humidification, dispersion of agricultural chemicals, and paint spraying. Therefore measurement of droplet size is important for atomization processes, nozzles, and their improvement. Several methods are used for this purpose: high-speed photography, light absorption and scattering, droplet freezing, and collection of droplets on coated slides and in immersion cells. Author presents a review of all these methods, and points out their advantages and disadvantages.

He investigates in detail the technique of immersion sampling which is used for scientific research, and also for industrial testing of atomizing devices. This method entails collection of dyed water droplets in sampling cells containing an immersion fluid with which the water is not miscible; photomicrographs of the droplets are then obtained and are evaluated by visual or by automatic counting. Limitations and error sources of this method are discussed: large, high-velocity droplets have a tendency to shatter at impact with the immersion fluid; very small droplets fail to impact on the cell; the shutter used to expose the cell to the spray interferes with the spray and changes somewhat its characteristics.

The author analyzes the mechanics of sampling of hollow-cone and solid-cone sprays, and from this draws conclusions regarding optimal cell and shutter configurations, sampling distance, and exposure time. These conclusions are summarized in several graphs; also numerical data are given of the characteristics of some typical sprays for oil burning and for spray drying. Finally, author discusses some special applications, such as impinging jets and spray clusters such as are used in gas turbines and rockets, and immersion liquids suitable for jet fuel.

This is an authoritative and up-to-date treatment of the subject, which is of considerable importance for the further development of combustion of liquid fuels, and for the improvement of other industrial spraying processes.

AMR 15-3678

T-13. Tate, R. W.

"Atomization by Pressure Nozzles" Ph.D. Thesis, University of Wisconsin. 1950

T-14. Tate, R. W. and W. R. Marshall

8046 Atomization by Centrifugal Pressure Nozzles. R. W. Tate and W. R. Marshall, Jr. *Chemical Engineering Progress* (Engineering Section), v. 49, Apr. 1953, p. 169-174; May 1953, p. 226-234; disc., p. 234.

Study was made to correlate spray characteristics of centrifugal pressure nozzles with their principal design and operating variables. Describes tests to observe effect of liquid viscosity upon drop-size distribution. Diagrams, photographs, graphs, tables. 31 ref.

BMI 2-8046

T-15. Taylor, E. H. and D. B. Harmon

2054. Taylor, E. H., and Harmon, D. B., Jr., Measuring drop sizes in sprays, *Indust. Engng. Chem.* **46**, 7, 1455-1457, 3 figs., 4 refs., July 1954.

A modification of the frozen drop method (as previously used by Longwell) is described, and preliminary results using water as the sprayed fluid are given. The spray is caught in a container filled with catching liquid—in this case hexane—kept at a low temperature, in this case minus 20 C, by means of dry ice. The container is fitted with a horizontal shutter located at a certain distance below the surface of the catching liquid, and with a catching pan located near the bottom of the container but suspended on the arm of a weighing balance. In operation the spray is directed upward, and in descending, lands first on the surface of the catching liquid and rapidly freezes, then settles on the horizontal shutter. After spraying, the frozen globules accumulated on the shutter are suddenly released and are allowed to fall on the submerged catching pan, and can be weighed by the balance. Because the fall proceeds according to Stokes' law, the weight-vs-time curve can be interpreted in terms of proportional weight of drops having certain size.

The differential density was 0.115 gram/gram H_2O; the range of Reynolds number was from 1 to 25; the depth of fall 12 inches. For these conditions the times of fall would range from about 4 minutes for drops of 100 microns to about 27 hours for drops of 5 microns diam. Method is comparatively rapid and requires no special sampling of spray. The theoretical and experimental test results showed reasonable agreement.

AMR 8-2054

T-16. Taylor, G.

114 FORMATION OF THIN FLAT SHEETS OF WATER.
G.Taylor.
Proc. Roy. Soc. A (GB), Vol. 259, 1-17 (Nov. 22, 1960).

A thin plane sheet of fluid which is limited laterally and converges toward a point transforms itself into a sheet which diverges in a perpendicular plane. When the angle of convergence is small and the distribution of thickness in the converging sheet is elliptic the diverging sheet has the same shape as the converging sheet. Apparatus for producing such a sheet was set up and the shape of the stream and distribution of pressure in the region of the transformation were measured and compared with calculations. The formation of thin sheets by the oblique impact of two cylindrical jets was studied and the distribution of thickness measured. The shapes of sheets corresponding to the measured distribution of thickness were calculated and compared with photographs.

PA 64-114

T-17. Taylor, G.

5297. Taylor, G., The dynamics of thin sheets of fluid, Parts 1, 2, and 3: Water bells; Waves on fluid sheets; Disintegration of fluid sheets, *Proc. Roy. Soc. Lond.* (*A*) **253**, 1274, 289-321, Dec. 1959.

In Part I, a general differential equation describing the shape of an axially symmetric sheet of fluid is presented. A closed solution is obtained for the simple case of equal pressure inside and outside of the water bell and of negligible gravitational effect. Calculated results compare very favorably with measurements. Effects of air friction were investigated using an analysis performed by Howarth. It is effectively the calculation of skin friction due to the adjacent laminar boundary layer in air.

In Part II, the behavior of capillary waves in thin fluid sheets is discussed. It is found that they are of two kinds: (1) antisymmetrical waves in which displacements of opposite surfaces are in the same direction and (2) symmetrical waves in which the displacements are of opposite direction. The antisymmetrical waves are nondispersive. When the thickness of the sheet t is small compared to wavelength λ, such waves are propagated at a speed independent of wavelength which is given by $\sqrt{\frac{2T}{\rho t}}$, T being the surface tension and ρ the fluid mass density. It is analogous to sound waves. In a sheet of uniform thickness moving with constant speed u, a point disturbance produces line-like waves at angles $\pm$ arc sin $\sqrt{W}$ to the flow direction, where W is the Weber number $\frac{2T}{\rho t u^2}$. When the sheet is expanding radially, the corresponding disturbances assume the form of cardioids. An interesting technique was described for photographing the wave patterns.

The symmetrical waves are highly dispersive and, as such, are more difficult to analyze. They are propagated at a much slower ence. An approximate treatment indicates that a point disturbance in a moving sheet of uniform thickness produces parabolic waves with their common axes lying downstream from the origin. The wave pattern due to the motion of a pressure point is also discussed. When the sheet is expanding, the waves are of a more complicated nature. Symmetrical wave patterns as revealed by schlieren photographs agree reasonably well with theoretical predictions.

In Part III, the problem of disintegration of free edge of thin fluid sheets is examined. From a consideration of the dynamics of the edge, author found that a straight free edge bounding a fluid sheet of uniform thickness moves at a speed equal to that of the antisymmetrical waves. Hence the angle between it and the direction of motion is again arc sin $\sqrt{W}$. Both waves and edge remain fixed in space. Photographs taken during experiments on antisymmetrical waves confirm this.

In a radially expanding sheet, there is a limiting radius R beyond which the sheet cannot extend. This occurs when the Weber number equals unity for an inviscid fluid and when there is no turbulence. The analysis agrees well with the experimental findings of Savart. It also indicates the feasibility of determining surface tension under dynamical conditions. *At or just prior to the attainment* of the critical radius, the edge becomes unstable and it breaks up into droplets. Calculation reveals that only a very small fraction of the kinetic energy in the original sheet was carried away by the drops in the form of surface energy. The main portion of it was dissipated through turbulence within the drops.

Edges formed by a small obstacle in an expanding sheet do not coincide with the cardioids described in Part II, if the free edge does not disintegrate. Equations were given for calculating its shape. On the other hand, if the edges break up into drops, they will assume the cardioid form.

Author concludes this part by considering the mechanism of disintegration of fluid sheets produced by a swirl atomizer. An expression for the order of magnitude estimation of the droplet size is given.

AMR 13-5297

T-18. Taylor, G. I.

1234. Taylor, G. I., The boundary layer in the converging nozzle of a swirl atomizer, *Quart. J. Mech. appl. Math.* 3, part 2, 129–139, June 1950.

The boundary layer along a conical surface immersed in a liquid swirling about the cone axis is studied. Flow inside boundary layer is assumed to be axially symmetrical with three velocity components. The simplified boundary-layer equations are then solved approximately by Pohlhausen's method. Improved solution to this problem was given later by A. M. Binnie and D. P. Harris.

AMR 4-1234

T-19. Taylor, G.

"The Instability of Liquid Surfaces when Accelerated in a Direction Perpendicular to Their Planes. I." G. Taylor. Proc. Roy. Soc. A 201, 192-6 (March 22, 1950).

T-20. Taylor, G. I.

2703. G. I. Taylor, The mechanics of swirl atomizers, Proc. seventh int. Congr. appl. Mech. 2, part I, 280-285 (1948).

Contribution discusses application of "perfect fluid" concept to flow through swirl atomizers. Author demonstrates from simple considerations that a perfect fluid theory is inapplicable. He concludes with the remark that his recent studies bear him out and indicate that "there is a strong axial flow along the core" of atomizer.

AMR 3-2703

T-21. Thew, J. P.

Drop Sizes in a Fuel Oil Spray as Influenced by Operating Conditions. J. P. Thew. M. S. Thesis, Penna. State Coll., 1931, 22 p., 25 fig., 4 tabl. Abstr. in Penn. State Coll. Eng. Exp. Sta. Bull. No. 40 (1932), pp. 21–25, 3 fig.

Measured drop size distribution by collecting drops in the tanning compound "Quaol", first described in WOELTJEN 1925 and counting drops under microscope. Determined weight-mean-drop diameters for Diesel engine operating conditions.

deJ I-343

T-22. Thiemann, A. E.

Die Zähigkeit der Luft ist wichtiger als ihre Dichte für die Kraftstoffzerstäubung (Viscosity of air has more influence than its density on the atomization of fuel). A. E. Thiemann. ATZ (Germ.) Vol. 37, No. 16 (Aug. 1934), p. 429, 3 fig.

T-23. Thomas, P. H.

1575. **Absorption and scattering of radiation by water sprays of large drops.** P. H. Thomas. *Brit. J. appl. Phys.*, 3, 385–93 (*Dec.*, 1952).

An investigation of the efficiency of water sprays in the protection of buildings and fire-fighting personnel from heat radiation has resulted in a general theoretical study of the transmission of radiation through a layer of water spray of large drops. The treatment is based upon the work of Theissing (1950) and takes account of multiple refractive scattering in dense sprays and extends the method to absorbing sprays. The problem of the single drop is approached from the point of view of geometric optics, from which approximate expressions are derived for the absorption of a drop in terms of the absorption index for any given wavelength and for the angular distribution of radiation transmitted by a single drop. Since the absorption of thermal radiation depends markedly on the drop size it is found that the transmission of such radiation departs from the simple exponential extinction law when the drops and the quantities of water in the sprays are small. When the drops are less than about 0·005 cm in dia., back reflection by the spray may become significant.

PA 56-1575

T-24. Thring, M. W.

236* The Combustion of Atomised Fuels. I. M. W. Thring. *Petroleum Times*, v. 59, Oct. 14, 1955, p. 1051-1055. Discusses droplet size, ignition delay, and combustion time of single droplets. Tables, graph. 17 ref. (To be continued.)

BMI 5-236

T-25. Tipler, W.

"The Measurement and Significance of Fuel Spray Momentum" Shell International Petroleum Co., Ltd., Oil Products Development Division. O.P.D. Report No. 202/62M. August 1962.

Summary. The merits of different types of swirl pressure jet atomiser with regard to quality of atomisation can be compared very quickly by the use of simple apparatus. Such comparisons, together with observations of spray uniformity ("patternation"), can assist in achieving and maintaining improved standards of combustion and plant efficiency.

The elementary equipment used for these investigations can also be used for more detailed studies of:

(i) Flow conditions within the atomiser itself, the overall discharge coefficient being expressed as the product of a velocity coefficient and an area coefficient, which are readily calculated from momentum measurements.

(ii) Fuel spray particle size—without the use of costly equipment or time consuming techniques.

(iii) Flame formation and radiant heat transfer.

Author

T-26. Tomotika, S. and T. Aoi

"The Steady Flow of Viscous Fluid Past a Sphere and Circular Cylinder at Small Reynolds Numbers" Quart. J. Mech. App. Math. 3, 140-61 (1950)

T-27. Tonks, L.

2651. **Instability and Rupture of Droplets and Bubbles in Strong Electric Fields.** L. Tonks. *Frank. Inst., J.* **221.** *pp.* **613–620,** *May,* 1936.—An approximate quantitative theory of the equilibrium of a bubble or droplet in a uniform electric field is developed and applied to earlier experimental results. An explanation of the oscillation of bubbles in strong fields and the difference in behaviour of positive and negative bubbles is explained on the basis of the discharge of electricity from points. [See also Abstract 3393 (1935).]

PA 39-2651

T-28. Townley, V. H.

THE USE OF A VENTURI ATOMIZER IN SPRAY DRIER DESIGN

(Publication No. 18,963)

Verne Howard Townley, Ph.D.
University of Minnesota, 1953

The object of the research was to increase the efficiency of spray drying heat labile materials by designing a spray drier which could use high temperature inlet air without damaging the product.

A spray drier has been designed which uses a venturi atomizer to produce a liquid spray and to mix the spray with the drying air. Most of the drying runs were made using an air velocity of approximately 900 feet per second at the throat of the venturi. Air velocities of less than 450 feet per second caused incomplete atomization and deposition of powder on the wall of the diffuser. The use of a diffuser increased the efficiency of the fluid flow so that 15 to 18 inches of water pressure was sufficient to produce the desired air velocity.

The venturi exhausted downward into a drying chamber. The overall effect was to provide immediate and complete mixing of the spray and drying air which then flowed concurrently through the drier to the cyclone separator.

The drier was used to manufacture non fat and whole milk powders at inlet air temperatures up to 535° F. with no deleterious effect on the product. Data are presented to show that the temperature of the inlet air has no effect on the solubility index of the powder if the exit air temperature is held constant. The powder did not contact the drier walls until the final stages of drying which prevented the formation of specks of burned powder.

Condensed milks containing from 24 to 54 per cent solids were dried. The powders dried from milks containing 45 to 54 per cent solids by inlet air at temperatures above 430° F. dispersed very readily without stirring when floated on the surface of water while normal powders did not disperse in this manner.

At a constant exit air temperature, the moisture content of the powder increased with increase in temperature of the inlet air and solids content of the condensed milk. Obviously, it was necessary to increase the rate of milk flow to hold the exit air temperature constant. This caused an increase in the humidity of the air and an increase in the size of the spray particles. A small pneumatic redrier was used to reduce the moisture content of the product to the desired level with no apparent damage to the powder.

The design of the drier is such that it should be possible to construct a commercial drier that would produce a superior product at higher efficiencies.

114 pages. $2.00. Mic 57-726

DA 17-458

T-29. Troesch, H. A.

3823. Troesch, H. A., The free fall of drops in air (in German), *Z. VDI* 105, 30, 1393-1397, Oct. 1963.

Author analyzes older published data on the free fall and breakup of liquid drops. Partly based on theoretical considerations (which basically turns out to be a dimensional analysis), a relation is proposed for the maximum stable dropsize expressed in terms of surface tension, velocity pressure of the relative air flow, the drag coefficient and the ratio of liquid to air viscosity.

The paper is in many details not clearly written. Not clear to reviewer is how a rotation of the deformed drop along its vertical axis can be induced by the toroidal secondary flow within the drop, as suggested. Also rather confusing is the comparison of the effect of liquid viscosity on drop deformation with the effect of fluid viscosity on the flow resistance of rigid bodies.

AMR 18-3823

T-30. Troesch, H. A.

3734. Troesch, H. A., Breakup of liquids and determination of drop size (in German), *Chemie-Ingenieur-Technik* 30, 10, 667–672, 1959.

In this brief survey of the requirements of various industrial, medical and other spray applications, various modes of droplet generation are discussed, i.e., by free fall, separation by jet breakup, separation by jet-wave formulation, and forced atomization. The first three occur at comparatively low pressure and velocity, and are amenable to experimental and theoretical analysis and to prediction of their characteristics; the fourth mode, atomization at high pressure and velocity, while technologically of the greatest importance, is difficult to investigate experimentally owing to the rapidity of the phenomenon, and it is not possible to predict the characteristics of the spray from the design data of the nozzle and from the properties of the liquid and of the air.

To be usable for the predetermination of drop size and drop-size distribution an experimental procedure must satisfy several requirements, namely: (1) the atomization must be unhindered by foreign bodies and by air currents, and it must be a continuous process; (2) at the location where the drops are collected, their velocity must be low enough so that the drops once formed do not break up further, and the globules do not deform; (3) the sample obtained must be a truly average and representative one; (4) the droplets or frozen globules must not be hollow; (5) the method must yield representative results; (6) between the atomization and the drop-size determination no evaporation of a component of the droplets should occur.

From the aspects of these requirements, author scrutinizes a number of methods used by previous investigators, i.e., various catching methods, spark photography, light absorption, photoelectric methods, and using a substitute material which is liquid when sprayed and is solidified when it is examined. He describes in detail his method of using wax as substitute material, the safeguards to observe for obtaining accurate and reproducible results, as developed in the laboratory of the Nestle Company. Procedure is outlined for evaluating and representing the results in such a manner that these results can form the basis for the rational design of spray-generating equipment.

This is an excellent critical survey giving an up-to-date list of the various methods used for the determination of the fundamental characteristics of sprays.

AMR 13-3734

T-31. Troesch, H. A.

TROESCH 1954

Die Zerstäubung von Flüssigkeiten. Hans A. Troesch (Eidgen. Tech. Hochschule Zürich). Chemie Ingenieur Technik. Vol. 26, No. 6 (1954), pp. 311–320, 6 fig., 44 ref. (Dissertation, Eidgen. Tech. Hochschule Zürich; Referent: Dr. P. Grassmann, Co-referent: Prof. Ackeret.)

The various types of atomizers are classified according to physical principles; using considerations of similitude, a formula is devised for the largest size drop produced by the atomization. The formula is based on the assumption that the break-up of drop is caused by rotationally symmetrical vibrations. Under further assumptions of energy-exchange between the drops in the atomizing space, with statistical considerations, the size-distribution function is determined for each type of atomizer, which is then applied to experimental results of the author and of previous workers. For certain types of atomizers it is possible to set up the drop-size distribution without experiments. Headings and contents of chapters: Characterization of atomizing nozzles according to physical principles; theoretical determination of the maximum size of drops formed; breaking up of liquid drops produced by rotation-symmetrical oscillations; comparison with experimental results; calculating the characteristic drop-size distribution; work of RAYLEIGH, WEBER, OHNESORGE, HAENLEIN, TRIEBNIGG, NUKIYAMA; probability theory and statistics; various kinds of characteristics; mean drop-size; frozen wax method.

deJ I-348

T-32. Troesch, H. A. and P. Grassmann

6524. The distribution law of particle size from atomization. H. A. Troesch and P. Grassmann. *Z. angew. Math. Phys.*, 4, *No.* 1, 81–5 (*Jan.*, 1953) *In German.*

Formulae are derived on classical statistics for the distribution of drops, their surface and volume. Two parameters are contained in the formulae, which fit the facts better than previous ones, the maximum drop diameter which can be calculated and the exchange factor which depends on the type of atomizer.

PA 56-6524

T-33. Tsui, J. B-Y

AD-463 730 Div. 27/2

Charged Particle Research Lab., Univ. of Illinois, Urbana.
ELECTROKINETIC PUMPING OF INSULATING LIQUIDS, by James Boo-yee Tsui. 15 Jan 65, 115p.
Rept. no. CPRL-1-65

Unclassified report

Prepared for Xerox Corp., Rochester, N. Y., under Grant AF-AFOSR-107-64 and Contract AF33 615 1459.

Descriptors: (*Jet pumps, Analysis), (*Liquids, Pumps), (*Electromagnetic pumps, Dielectrics), (*Drops, Production), Theory, Electric fields, Magnetic fields, Design, Numerical analysis, Pressure, Ion sources, Statistical mechanics, Spheres, Motion, Ionic current, Thermionic emission, Dissociation, Reviews, Viscosity, Recombination reactions, Series, Experimental data, Test equipment, Bibliographies.

This work is concerned with the ion drag pump. It includes theoretical studies, experimental studies and applications of the pump. From the observation of the motion of liquid between the electrodes of the ion drag pump, a physical picture of the pump operation is assumed. Through the basic physical picture, another type of ion drag pump is suggested in which both electric and magnetic fields are used. An analysis of this pump is carried out. It may prove to have a better efficiency than the electric field pump. Since the pressure generated by the pump is rather low, it can only be used practically in a few limited cases. To break a cylindrical liquid jet into uniform sized droplets a very small sinusoidal pressure variation is needed.

The ion drag pump can generate such pressures and results of experimental work are presented which describe the use of an ion drag pump to synchronize the break-up of a jet into uniform drops. Measurements of charge on the drops indicate that the ion drag pump influences the production of droplets without charging the drops. (Author)

TAB 65-13

T-34. Tsutsui, T.

Rupture Phenomena of Liquid Drops. T. Tsutsui. Tokyo Imp. Univ. (Japan) Scie. Papers, Inst. Phys. and Chem. Res., Vol. 16 (1931), p. 109.

Rupture phenomena of drops falling on horizontal surfaces. Effect of surface roughness and liquid viscosity.

deJ I-349

T-35. Tsyurupa, N. N. and A. I. Terekhora

"Types and Classification of Disperse Systems" Russ. J. Phys. Chem. 38, No. 7, 963-5 (July 1964)

T-36. Turba, J.

"The Significance of Stream Atomization and a Theoretical Treatment of the Mechanism of Jet Disintegration." Jozsef Turba (Polytech. Univ., Budapest, Hung.). Magy. Kem. Lapja 17, 127-30 (1962).

CA 57-7057h

T-37. Turner, G. M. and R. W. Moulton

"Drop-Size Distribution from Spray Nozzles." G. M. Turner and R. W. Moulton (Univ. of Washington, Seattle). Chem. Eng. Progr. 49, 185-90 (1953).

CA 47-5177i

T-38. Tyler, E.

Instability of Liquid Jets. E. Tyler (Leicester Coll. of Technology). Phil. Mag. (Engl.), Vol. 16 (1933), pp. 504–518, 10 ref.

Spark photography method of examining the degree of instability of capillary jets. Measurements of drop size and spacing of drops just formed, using mercury, aniline and colored water, in order to test influence of density, surface tension and viscosity. Frequency of drop formation was experimentally determined using (a) a photoelectric cell, (b) flashing neon tube, and (c) mechanical stroboscope. Comparison with theory showed fair agreement.

deJ I-350

T-39. Tyler, E. and E. G. Richardson

The Characteristic Curve of Liquid Jets. E. Tyler and E. G. Richardson. Proc. Phys. Soc. (Engl.) Vol. 37 (1925), pp. 297–311.

Experiments on break-up distance of low-speed jets in relation to jet velocity. Effect of surface tension and viscosity on break-up distance.

deJ I-350

T-40. Tyler, E. and F. Watkin

TYLER and WATKIN 1932

Experiments with Capillary Jets. E. Tyler and F. Watkin (Leicester Coll. of Techn.). Phil. Mag. (Engl.) Series 7, Vol. 14, No. 94 (1932), pp. 849–881; 5 tables, 5 ref.

Effect of surface tension and viscosity on break-up distance; velocity characteristics of capillary jets. An inverted glass bottle contained the liquid; it was connected to a large reservoir containing air under variable pressure which was measured with a pressure gauge. The nozzle was attached to the mouth of the bottle. Relation of unbroken length of the jet vs. its velocity of efflux from a cylindrical capillary nozzle is determined for liquids having different specific gravity, viscosity and surface tension, and represented in numerous graphs. Influence of surrounding medium by injection into other non-miscible liquids. Dimensional formulas. Paraffin, aniline, water, turpentine and mercury were also used.

deJ I-350

U-1. Uberoi, M. S., and C. Y. Chow

21950 INSTABILITY OF A CURRENT-CARRYING FLUID JET ISSUING FROM A NOZZLE.
M.S.Uberoi and Chuen-Yen Chow.
Phys. of Fluids (USA), Vol.6, No.9, 1237-41 (Sept., 1963).

The velocity across a jet becomes nonuniform due to contraction or expansion of fluid in the presence of electric current within the nozzle from which it issues. The results obtained elsewhere on the instability of a jet of uniform velocity due to electric current and surface tension are corrected. It is further shown that velocity nonuniformity reduces this instability. The available data on the instability of a mercury jet issuing from a contraction are for small current density and, hence, low velocity nonuniformity. However, for reasons yet unknown, the data do not agree with the (corrected) theory for the case of uniform velocity.

PA 66-21950

U-2. Ueyama, K.

"Size of Drops Formed at the End of Single Nozzles." Koretsune Ueyama (Univ. Osaka Pref.). Kagaku Kōgaku 21, 766-74 (1957).

CA 52-5050g

U-3. Ullrich, H.

463. Ullrich, H., Flow phenomena in swirl-type burners having a controllable swirl, and with rotation-symmetrical free jets (in German), *Forsch. Geb. Ing.-Wes.* 26, 1, 19-28, 1960.

This is the second, experimental, part of an extensive investigation of air-flow phenomena in swirl-type burners. The experimental layouts for swirl-type, and for swirlless nozzles, are illustrated and described; dimensioned drawings are shown of the nozzles (round, annular, and conical nozzles without swirl, and one conical nozzle with swirl). Dimensioned drawing of the pressure-measuring pitot-tube is also given. Graphs are shown of the streamlines from an annular nozzle without swirl, of the static pressure and velocity values at various radial and axial positions in the stream. Characteristic curves are given also for the air flow from a nozzle with swirl. The stability of possible stream configurations—full stream, annular stream, and wall stream—is discussed, and represented in graph. Author concludes that for swirl-free flow the conditions can be calculated with fair approximation to theory, but for flow with swirl the calculation does not yield good agreement because the instabilities caused by the swirl produce asymmetrical flow configurations.

Inasmuch as the experiments were carried out without combustion, the results are not fully applicable to a burning flame; nevertheless some useful conclusions can be drawn also for flow under combustion conditions. It is pointed out that the experiments were made in free space, while combustion takes place in an enclosed space; therefore the experimental results can be applied to a combustion space only if the nozzle diameter is small compared with the dimensions of the combustion space, and the flow is not near to a wall surface. Keeping these differences and restrictions in mind the theories and experiments described can serve as guidance in estimating the conditions under combustion.

AMR 14-463

U-4. Ullrich, H.

462. Ullrich, H., Mechanism of flow in swirl burners with adjustable swirl and in free jets of rotational symmetry (in German), *Forsch. Geb. Ing.-Wes.* 25, 6, 165-181, 1959.

A complete study was made of nozzle flow technology for fuel gas, oil, and coal-dust used in steam generation. A new type swirl burner is described which uses conical ring jets. Estimates of the burning constants were made through research. Further theoretical and experimental determinations give the behavior of the different stream configurations issued from cylindrical or conical ring jets, with and without twists. Assuming frictionless flow at the center of the stream and end pressures, the flow contour was calculated. It was found the flow from a simple round jet as well as cylindrical or conical ring jets was well known as long as the output was without twist. Twisted streams occurred from small imperfections in the jets and were heretofore thought due to unsymmetry in the flow current. The results of these studies have been applied and tested in a steam generator.

AMR 14-462

U-5. Ul'yanov, I. E.

"The Breaking Down of Liquid Fuels in the Atomization Nozzles." I. E. Ul'yanov. Izvest. Akad. Nauk. S.S.S.R., Otdel. Tekh. Nauk 1954, No. 8, 23-8.

CA 49-5808g

U-6. U.S. Army Chemical Corps

A Basic Study of the Physics of Aerosol Formation. Bibliographic Appendix. Final Tech. Rep., U.S. Army Chem. Corps Labs., Contr. No. DA-18-064-CML-1402, July 1, 1953, 210 p., 676 annotated ref., subject index.

Enlarged edition of DeJUHASZ 1948, compiled at Pennsylvania State College, Spray Res. Lab. (K. J. DeJUHASZ, Professor-in-Charge). Topics include: application of sprays, chemistry and physics of sprays, atomization, atomizers, mechanical properties of sprays, solid particles, theory and fundamentals.

deJ II-104

U-7. Uvarov, G. A.

"Entrainment of Liquid by Gas or Steam," Sborn. nauch. Trud. Kuibyshevsk. industr. In-ta 5, 196-203 (1955), Trans. available: TIL/T.5028 or NACA N 82289, issued Dec. 1959 by T.I.L.

V-1. Valdenazzi, L.

1836. Valdenazzi, L., On the form of a jet issuing from a swirl atomizer, *Ing. Arch.* 24, 5, 330-340, 1956.

A rigorous treatment, with detailed derivations, of the liquid cone issuing from a swirl atomizer, and its subsequent break-up into droplets, is presented under the following assumptions: (a) the flow is continuous; (b) the liquid is inviscid; (c) the energy of flow is constant; (d) the fluid into which the jet enters does not affect the flow, and is of constant pressure; (e) the liquid motion is symmetrical about the axis. In other words, mainly the surface tension forces and the inertia forces are taken into consideration. The functions obtained are also reduced to dimensionless form. The case of very high Weber number is treated, i.e., when the surface tension forces are negligible in comparison with the inertial forces. The influence of the Weber number on the unbroken liquid surface is shown. Reference is made to the papers of Soehngen and Grigull, Doumas, and Weinberg.

AMR 10-1836

V-2. Van Rossum, J. J.

"Experimental Investigation of Horizontal Liquid Films: Wave Formation, Atomization, Film Thickness," Chem. Eng. Sci. 11, 35-52 (1959).

Abstract—The entrainment, wave formation and atomization of horizontal films of water, aqueous solutions and oils have been investigated.

The mean film thickness measured has been compared with the theoretical film thickness for laminar liquid flow and a smooth gas-liquid interface. Over a wide range of conditions the mean actual film thickness is about 0·8 times the theoretical one.

The critical velocities for the onset of waves and atomization were determined at different liquid flow rates. The critical conditions for atomization have been analysed in two ways, in a correlation involving the Weber number (which includes the film thickness), or in a correlation involving the Reynolds number for film flow (which includes the rate of liquid flow).

Author

V-3. Venkata, R. S A.

THE PRODUCTION, MOVEMENT AND EVAPORATION OF SPRAYS IN SPRAY DRYERS.

(L. C. Card No. Mic 59-5454)

Venkata Rao Sahib Arni, Ph.D.
University of Washington, 1959

Preliminary investigations dealing with the possibility of using an existing four-foot diameter pilot-scale spray dryer for evaporation studies indicated unfavorable velocity distributions within the drying chamber. A tower-type spray dryer, 24 feet high and 8 inches in diameter, was constructed to offset this disadvantage. The first stage of this study was related to the effect of the air-entry design on the velocity profiles in the two dryers. A subsequent study was made to determine the influence of physical and chemical properties of liquids on the disintegration of viscous jets. As a result of this work, potassium carbonate solutions and nitrobenzene were selected as suitable spraying materials for an investigation of evaporation rates. The subject matter of the thesis is divided into three separate but related parts.

Part I. The Effect of Air-Entry Design on the Distribution of Velocities in Spray Dryers -- A single-coil hot-wire anemometer was constructed and used along with a suitable Kelvin-Bridge to determine velocity profiles in a chamber-type dryer designed by Buckham and Moulton and in the tower-type spray dryer. The former had a straight air-entry system with an eight member web-type distributor for dispersing the air. The tower dryer was also installed with a straight air-entry but was provided with a set of two 60-mesh screen distributors. The data for the chamber dryer showed highly peaked velocity distributions, the maximum velocity being attained in the neighborhood of the central vertical axis. The magnitude of the peak velocity, (1) was several fold higher than average dryer velocity, (2) varied with vertical position, (3) diminished with decreasing inlet velocity, (4) varied with angular position. The shape of the profile, (1) was conserved for varying flowrates, (2) remained unaltered for a major portion of the dryer height, and (3) was little affected by the design of the air-exit system. The flow pattern was ascribed to the jet-type action of the inlet duct, the web-distributor being almost totally ineffective. The data also indicated stagnant pockets of air in the drying chamber. The tower-dryer showed relatively uniform flow patterns for a considerable portion of its length. In the vicinity of the distributors, however, a vertical flow pattern was shown to exist, the vortex decaying rapidly with distance.

Part II. The Influence of Structural Variants on the Disintegration of Varicose Jets -- Ionic solutions, such as potassium carbonate solutions, when sprayed from hypodermic nozzles produced arrays of droplets whose volume- and geometric-mean diameters deviated considerably from empirically based correlations in literature. The volume-mean diameters for organic sprays were found to be dependent more on the dipole moment and molecular configuration of the liquid species than on its physical properties and associated flow variables. Sucrose solutions yielded drops whose diameters were in between those of ionic and organic sprays. In most cases, drop distributions based on number showed bimodal characteristics. Several possible mechanisms are suggested and discussed. For varicose jets of nitrobenzene, the volume-mean drop diameters were found to be only slightly dependent on flowrate. The drop diameter was shown to be sensitive to nozzle diameter. The spread of drop sizes was found to vary with both nozzle diameter and flowrate, increasing with either factor. The available data permitted the calculation of disintegration wave lengths. These were shown to vary slightly with flowrate and/or nozzle diameter. An equation was derived which permits the calculation of the largest population segment of a possible spectrum of droplets from varicose disintegration.

Part III. Studies on the Evaporation of Sprays in Relative Motion to a Concurrent Stream of Hot Air -- The tower spray dryer was used to determine the extent of evaporation of potassium carbonate and nitrobenzene sprays. The liquid nitrogen freezing technique was used to study the pre- and post-evaporation droplet distribution data. The data for potassium carbonate sprays was compared with theoretical predictions for single drops, the surface-mean diameter of the spray being used as a model-drop evaporating under the conditions obtaining for the spray. The experimental data showed higher rates of evaporation than that predicted for the model. The relative shift of the pre-and post-evaporation distribution curves also indicated higher rates of evaporation. It was concluded that droplet oscillation, distortion, acceleration and spin were responsible for the higher rates. Quantitative analysis of the decrease in diameter was not attempted since the primary variables, such as droplet distribution and mean diameter were relatively insensitive to variations in nozzle diameter and liquid flowrate. Droplets much smaller than those of potassium carbonate and more effectively distributed were found to occur in the disintegration of nitrobenzene jets. This liquid was therefore sprayed and the evaporation, as manifested in the shift of the distribution curves, was compared to that predicted for the simultaneous vaporization of discrete sets of droplets. The results of these computations showed the inapplicability of the method to sprays. It was concluded that interactions between droplets and screening effects definitely affect the evaporation rate. The application of this technique to the evaporation of potassium carbonate sprays showed, however, the expected trends.

Microfilm $4.00; Xerox $13.60. 312 pages.

DA 20-3231

V-4. Vereshchagin, L. F., et al

"On the Problem of the Breakup of High-Speed Jets of Water," Soviet Phys.-Tech. Phys. 4, 1, 38-42, July 1959. (Translation of Zh. Tekh. Fiz. 29, 1, 45-51, Jan. 1959 by American Institute of Physics, New York, N.Y.)

V-5. Vereshchagin, L. F., et al

"Investigating Water Jets Discharged through Nozzles at up to 2000 Atmosphere Pressure" (in Russian), Izv. Akad. Nauk SSSR, Otd. Tekh. Nauk no. 1, 57-60, Jan. 1957.

V-6. Vereshchagin, L. F., et al

Vereshchagin, L. F., Semerchan, A. A. and others. SOME INVESTIGATIONS ON A HYDRODYNAMIC JET OF LIQUID FLOWING FROM A NOZZLE AT PRESSURES UP TO 1,500 ATM (Nekotorye Issledovania Gidrodinamiki Strui Zhidkosti, Vytekayushchie iz Sopla pod Davleniem do 1500 AT). Sep 60 [9]p. 8 refs. TIL/T. 4832; [DSIR LLU] M. 2619; AD-244 047. Order from OTS or SLA $1.10 61-23393

Trans. of #Z[hurnal] Tekh[nicheskoi] Fiz[iki] (USSR) 1956, v. 26, no. 11, p. 2570-2577.

DESCRIPTORS: Hydrodynamics, Nozzles, *Liquid jets, *Fluid flow, Velocity, Pressure, Joule-Thomson effect, Compressore, Hydraulic systems, Mathematical analysis, Water.

It has become possible to produce a continuous jet of water issuing from a nozzle of special profile under high pressure. Investigations of this jet have demonstrated that even at a speed of the order of 500 m/sec the jet remains compact. In attaining a velocity approaching the speed of sound in air disturbances arise in the jet. The length of standing waves along the jet increases with increase in velocity, but disturbances are absent. Throttling of the liquid which is under pressure leads to heating of the liquid, which is apparently due to the negative Joules-Thompson effect.

T6-779

V-7. Viilu, A.

1590. Viilu, A., An experimental determination of the minimum Reynolds number for instability in a free jet, *Trans. ASME* 84 E (*J. Appl. Mech.*) 3, 506-508, Sept. 1962.

Brief description, mainly of experimental detail, of critical Reynolds number determination for stability of liquid-into-liquid jet. Critical value given in the range 10.5 to 11.8, with average error within 5 percent.

This forms only a part of the stability behavior, and reference should also be made to Reynolds, *J. Fluid Mech.* 14, 4, 552-556, Dec. 1962.

Reviewer would have liked a clearer physical discussion of observations, and particularly of any possible relationship between author's "slightly unstable" and "unstable" modes.

AMR 16-1590

V-8. Vitman, L. A.

2962. Vitman, L. A., Investigation of the density of irrigation by an atomized jet of liquid (in Russian), *Sb. nauch. rabot Leningr. s-kh. in-ta, Inzh. fak.* 11, 101-113, 1955; *Ref. Zh. Mekh.* 1956, Rev. no. 2820.

Data are given of the experimental investigation of the distribution of a liquid in an atomized jet of a solution of glycerine of three concentrations at various distances from the mouth of a pneumatic atomizer for three atomizers at small air velocities.

The assessment of the distribution of the liquid in a jet was effected by collecting the liquid in measuring glasses placed at various distances from the mouth of the atomizers and at different radii with subsequent weighing on analytical scales. The atomizers were placed vertically with the opening downwards.

The density of the irrigation was calculated, i. e., the amount of liquid falling per unit of time per unit of surface, perpendicular to the axis of the jet.

An approximate formula of the relationship of the relative density of irrigation g_x/g_{0x} to the distance from the axis of the jet r was obtained in the form

$$\frac{g_x}{g_{ox}} = \exp.\left[-0.7\ \frac{r}{r_{ox}}^{1.6}\right]$$

where g_x and g_{ox} are the density of irrigation at a given point of the section and on the axis of the jet, r_{ox} is the distance from the axis of the jet to the point of the section in which the density of irrigation is equal to 0.5. Graphs are given which show that this treatment makes it possible to generalize the data according to the densities of irrigation of the various liquids obtained for sections which are at varying distances from the mouth of the atomizer in different working conditions.

Author subdivides the process of atomizing the liquid by a pneumatic atomizer into the following three successive stages: breaking down the jet into drops with subsequent breaking down of large drops into smaller ones, acceleration of the drops as a result of interaction with the air current, and, later, transportation of the drops by the air current.

Author derives the relationship of the relative density of distribution of the liquid to criteria of similarity which determine the process of atomization and transfer of the liquid in the jet of air, taking as constant the coefficient of turbulent diffusion for various points of the jet, sufficiently removed from the nozzle.

AMR 10-2962

V-9. Vivdenko, M. I., and K. N. Shabalin

"The Mechanism of Jet Breakup Into Large Drops," Int. Chem. Eng., 5, 6-1-5 (Oct, 1965).

High-speed movies show that the breakup of a jet at a given cross-section occurs without reversible oscillations at this cross section, by means of contractions and expansions.

Author

V-10. Volynskii, M. S.

6755. Volynskii, M. S., Investigation of the atomization of a liquid in supersonic flow (in Russian), 3-e Vses. Soveshchanie po Teorii Goreniya (3rd All-Union Conference on the Theory of Combustion), Moscow, 2, 19-28, 1960; Ref. Zh. Mekh. no. 8, 1961, Rev. 8 B 227.

Atomization of fuel in supersonic flow is studied (jet form, evaluation of drop size, etc), and the physical peculiarities of the process are analyzed. An apparatus with a supersonic flow (Mach 2.0-2.7) was used for making the experiments. The forms of the atomization jet and of the shock wave were investigated using a Töpler device. The initial part of the jet boundary and the drop motion trajectories were determined with the aid of an approximate system of similarity criteria.

AMR 16-6755

V-11. Volínskiĭ, M. S.

2118. M. S. Volínskiĭ, Investigation of drop disintegration in a gas stream (in Russian), Doklady Akad. Nauk SSSR 68, 237-240 (1949).

This work continues that described in preceding review. Smallest drop size investigated was 0.273 mm, so that this and the previous work covered range of diameters from 0.273 mm to 3.9 mm. A specially constructed drop generator was used which produced drops of a given size with an accuracy of ± 0.01 mm. A rough theoretical analysis gives $\rho V^2 d/\sigma = D/[1 - (d_{min}/d)^{1/2}]^2$ where $10.7 < D < 14$ defines range of partial disintegration as found in previous work, and d_{min} is the limiting drop diameter for which no disintegration occurs. By use of above values of D and the empirically determined d_{min}, good agreement between theory and experiment was found.

AMR 3-2118

V-12. Volínskiĭ, M. S.

2117. M. S. Volínskiĭ, On the disintegration of liquid drops in an air stream (in Russian), Doklady Akad. Nauk SSSR 62, 301-304 (1948).

Experimental investigation in which individual drops 2 to 3.9 mm in diameter were dropped into an air jet to investigate factors affecting disintegration of the drops. The parameter $D = \rho V^2 d/\sigma$, where ρ is air density, V jet velocity, d diameter, and σ capillary constant, was found to be significant for drop sizes involved. For $D < 10.7$ no disintegration occurred; for $10.7 < D < 14$ disintegration was partial, i.e., near lower limit a few drops split in half followed by further splitting. For $D > 14$ the drops split immediately into many drops. Drops of mercury, water, tetrabromoethane, kerosene, ethyl alcohol, and gasoline were used in the experiments. Reynolds numbers for the drops were between 1700 and 8500.

AMR 3-2117

V-13. Vonnegut, B., and R. C. Neubauer

"Supplement to Production of Monodisperse Liquid Particles by Electrical Atomization," J. Colloid Sci. 8, No. 5, 551-2 (Oct. 1953).

V-14. Vonnegut, B., and R. Neubauer

"Detection and Measurement of Aerosol Particles by the Use of an Electrically Heated Filament," Anal. Chem. 24, 1000-5 (1952).

Investigations in cloud physics indicated the need for an instrument to detect and measure certain types of aerosol particles. When a gas containing a suspension of vaporizable particles is rapidly drawn past a small electrically heated filament, a cooling effect is produced by the sudden evaporation of each aerosol particle that collides with the filament. The resultant cooling of a portion of the heated filament produces a momentary lowering of its electrical resistance which is a function of the heat required for vaporization of the particle. This change of resistance produced by the particle can be readily transformed into a voltage pulse. By electronic techniques, the pulses can be counted and analyzed to give information concerning the concentration of particles, particle size, and the mass concentration of the dispersed substance.

Author

V-15. Vonnegut, B., and R. L. Neubauer

5175. **Production of monodisperse liquid particles by electrical atomization.** B. VONNEGUT AND R. L. NEUBAUER. *J. Colloid Sci.*, 7, 616-22 (*Dec.*, 1952).

Streams of highly electrified uniform droplets about 0·1 mm in diameter can be produced by applying potentials of 5–10 kV a.c. or d.c. to liquids in small capillaries. Monodisperse aerosols having a particle radius of a micron or less can be formed if the capillary is positively charged and if liquids having low electrical conductivity are used. Aerosols formed in this way show the colours of higher-order Tyndall spectra.

PA 56-5175

V-16. Vörös, I.

A cirkuláció és a kapilláris erök szerepe a cseppképzésben permetező szórófejeknél (Effect of circulation and of capillary forces in the production of spray droplets in agricultural spray nozzles). Imre Vörös. Diss., Inst. of Techn. Budapest (Hung.), 1935, (Springer-Press, Budapest). 55 p., 46 fig., 6 ref. (Engl. transl. by K. S. De Juhasz.)

Phenomena of atomization; design of agricultural swirl nozzles and the nature of flow within them; hydrodynamic theory; circulation; distribution of pressure; motion of fluid within the orifice and outside of it; the fluid stream is of hyperboloid shape after leaving the orifice ,but this shape is influenced at low velocities by capillary forces; distribution and dispersion of spray; quantity of discharge versus pressure; spray distribution was measured by spraying the colored liquid on a white paper, and by catching the spray in a tray subdivided into many radial and circumferential segments; energy of spray was measured by a large flat plate suspended as a pendulum; contraction of the liquid jet; nozzles with two coaxial sprays; nozzle with variable circulation.

deJ I-359

V-17. Vulis, L. A.

"Procedings of the Conference on Applied Gas Dynamics, 1956," Alma-Ata: Izdatel-Akad. Nauk Kazakh. S.S.R. (published 1959).

W-1. Wada, Y.

948. Wada, Y., On the recurrent figure of a jet, *J. phys. Soc. Japan* 7, 2, 211-214, Mar./Apr. 1952.

Author considers the standing waves on the surface of a circular jet and demonstrates that for a given mode there exists a minimum velocity which is inversely proportional to the radius of the jet. Using the results of a previous computation [title source, 5, 1950], he is able to extend Rayleigh's results for the jet [*Proc. roy. Soc.* 29, 1879] to show that, with increasing velocity, waves of successively higher mode are superposed, and that, above the minimum velocity, two wave lengths are coexistent, in analogy to Rayleigh's results for a plane surface [*Proc. Lond. math. Soc.* 15, 1883].

AMR 6-948

W-2. Wada, Y.

2415. On the standing varicose and sinuous ripple of a cylindrical flow. Y. WADA. *J. Phys. Soc. Japan*, 5, 439-42 (*Nov.-Dec.*, 1950).

An obstacle in the free surface of a cylindrical jet of fluid causes ripples upstream of the obstacle. The various possible types of standing wave are investigated theoretically, without assuming axial symmetry. There is experimental confirmation of the possibility of a sinusoidal vibration of the jet, with a wavelength increasing as the velocity of flow decreases.

PA 54-2415

W-3. Walker, V.

3100. Walker, V., Distribution of insoluble additive particles in a fuel spray, *Fuel* 35, 2, 153-160, Apr. 1956.

Given a mixture of solid, insoluble additive particles in a fuel oil, the object of the investigation was to determine to what extent the ratio of additive to fuel in the spray would vary from the over-all ratio in the mixture. Using known data about the distribution of particle sizes in the additive powder and the distribution of fuel droplet sizes in a spray, together with an assumption concerning the nature of the fuel-additive mixture, the problem was solved by elementary statistical reasoning. A set of curves has been constructed by means of which suitable combinations of over-all additive to fuel ratio, and additive powder and fuel spray finenesses can be selected. Chapters: Concept of mixture; Particle distribution functions; Distribution of additive particles in the spray; Results presented in a family of curves expressing the evenness of additive distribution in the spray as ordinate, versus the proportion of additive to fuel as abscissa.

AMR 9-3100

W-4. Walton, W. H. and W. C. Prewett

The Production of Sprays and Mists of Uniform Drop Size by Means of Spinning Disc Type Sprayers. W. H. Walton and W. C. Prewett (Chem. Defence Exper. Station, Porton, Wiltsh., England). Proc. of Phys. Soc., Sect. B. Vol. 62, Part 6, No. 354B (June 1949), pp. 341-350, 8 fig., 8 ref.

Spray of almost uniform drop-size is formed when liquid is fed onto the centre of a rotating disc and centrifuged off the edge. This method of spraying has been studied over a wide range of variables; homogeneous clouds have been produced in the drop-size range of 0.015 to 3.0 mm dia. Size of spray drops is given approximately by: $d = 3.8\,(\tau/D\rho)^{1/2}/\omega$ where d = drop dia., D = disc dia., ω = angular velocity of disc, τ = surface tension of liquid, ρ = density of liquid. The spray thus formed contains a proportion of fine satellite drops; their smaller distance of travel from the disc makes possible their removed from the cloud when their presence is undesirable. Relatively coarse sprays are easily produced by an electric motor driven disc. Finer sprays require rotor speeds of 1000 rpm. or more, obtainable by means of an air-driven "top"; apparatus of this kind is described. Influence of rate of liquid feed, of disc speed, and of other variables on drop size have been investigated and are represented in charts.

deJ I-365

W-5. Walton, W. H. and W. C. Prewett

Spinning Disc and Spinning Top Sprayers for the Production of Homogeneous Sprays and Mists. W. H. Walton and W. C. Prewett. Porton Tech. Paper No. 14 (Aug. 1947), 21 p., 14 fig.

Spray of nearly uniform drop size is produced when liquid is fed onto the centre of a rotating disc and centrifuged off the edge. Designs of motor-driven spinning disc and air-driven spinning-top sprayers, the latter capable of giving speeds up to several thousand revolutions per second, have been developed. Homogeneous clouds of droplets down to about 15 micron can be produced by these methods. Design of rotors has been studied; methods for eliminating satellite droplets are described. Theory of production of drops by the spinning disc or top has been considered. Diameter of drop is represented by the formula, $d = K\frac{1}{\omega}\sqrt{\tau/D\rho}$ where d = drop diameter, D = disc diameter, ω = angular velocity of disc, τ = surface tension of liquid, ρ = density of liquid. Average value of K is 3.8.

deJ I-364

W-6. Watson, E. A.

WATSON 1948

Fuel Systems for the Aero-Gas Turbine. E. A. Watson (Jos. Lucas, Ltd. Birmingham, Engl.). Proc. Inst. Mech. Eng. (Engl.), Vol. 158 (1948), pp. 187-208, 32 fig. Abstract: Engr. (Engl.), Vol. 184 (1947), pp. 561-563, 576 to 577, 11 fig.

Requirements for fuel systems for turbo-jet engines; describes several systems. Discusses action of swirl-chamber type atomizers and sprays obtained from them. Calculation of discharge coefficients and cone angles. Describes and shows figures of various flow-range nozzles, in particular the duplex nozzle and spill nozzle, and discusses their operation and performance. Original reference contains discussion by several research workers.

deJ I-365

W-7. Watson, E. A.

"Design of Swirl Atomizers - Tangential Type"
Joseph Lucas Res. Labs., Report No. L-1378,
File No. 20/168, Ref. EAW/HMS. Nov. 3, 1944

W-8. Weber, C.

Zum Zerfall eines Flüssigkeitsstrahles (Disintegration of Liquid Jets). C. Weber. Z. angew. Math. and Mech. (Germ.), Vol. 11, No. 2 (Apr. 1931), pp. 136—154, 22 fig.

Theoretical analysis of disintegration of non-viscous and viscous liquids under the influence of sur[illegible] and air resistance at comparatively low velocity. Theory agrees with Haenl[illegible] [illegible]ntal results.

Translation available in Ninth Progress Rept., Project No. MX-833, Sect. II, Univ. Colorado, Boulder.

deJ I-366

W-9. W[illegible]bull, W.

A Statistical Distribution Function of Wide Applicability. W. Weibull (Bofors, Sweden). Jl. Appl. Mech., Vol. 18, No. 3 (1951). pp. 293—297, 7 fig., 7 ref.

Gives a distribution function $F(x) = 1 - e^{-\left(\frac{x - x_u}{x_0}\right)^m}$ where F(x) is also the probability of choosing at random an individual having a value of $\underline{X} \leq x$, $\underline{X}$ being a variable attributed to the individuals of a population. Xu and X_0 are parameters having the same dimensions as x; m is a dimensionless constant. This distribution function has been applied successfully to a wide variety of problems, including size distribution of fly ash.

deJ I-366

W-10. Weinberg, S.

1648. Weinberg, S., Heat transfer to low pressure sprays of water in a steam atmosphere, *Instn. mech. Engrs. Proc. (B)* 1B, 6, 240-253, 1952.

The mechanism of water flow and atomization in low-pressure swirl-chamber nozzles was investigated. Measurements of the rate of heat transfer from steam to water both in the film phase and in the drop phase were made. Measurements of the length and velocity of the film formed by the water as it emerges from the nozzle orifice were made and simple correlations developed. Droplet sizes were measured and correlated with the nozzle size and pressure drop. Temperature measurements in the film phase disclosed that 70 to 90% of the possible heat transfer from the steam to the water took place in the film phase. The percentage transferred to the film was a function of nozzle pressure drop and decreased rapidly as the pressure drop increased beyond one atmosphere. Heat-transfer rates appear to be higher for the film than for the droplets, but the data are not conclusive because of uncertainty concerning the actual surface area in the film phase.

Reviewer believes that the author has somewhat overextended his data to reach general conclusions; a situation which is taken up at length in communications following the paper. His techniques seem quite good and the extension of them to higher pressure nozzles, etc., is desirable.

AMR 7-1648

W-11. Weiss, M. A.

ATOMIZATION IN HIGH VELOCITY AIR STREAMS

(L. C. Card No. Mic 60-5840)

Malcolm A. Weiss, Ph.D.
Columbia University, 1958

An experimental study was made of the drop size distributions resulting from spraying liquids into large air streams of sustained high velocity. The intent was to simulate fuel injection in turbojet afterburners and in ramjets; a knowledge of the drop sizes obtained would help in the design of jet engines and their fuel systems.

In the tests, a molten synthetic wax was injected along the axis of an air duct 6 inches in diameter. Wax and air temperatures were always equal to prevent ambiguity about temperature (and fluid properties) while drop breakup was still occurring. Downstream, a probe was used to withdraw a sample of air and droplets. The probe could be fixed locally or could move on a traverse path across the sampling plane. Air entered the probe isokinetically; inside, the stream was cooled and the wax droplets were frozen. The probe was proved to give a representative sample of the spray by several techniques. One was microscopic examination of the solid droplets (there was negligible distortion); another was collection of "sprays" of solid particles (the analyses were the same for samples fed and collected).

The collected particles were analyzed by sedimentation in air in the Micromerograph, a commercial analyzer. (Sieves were used to classify particles larger than 150 microns.) For calibration, the images on enlarged photomicrographs of eleven spray samples were sized and counted. The calibration showed that the sedimentation mass median diameters had a standard deviation of less than 8% from the photomicrographic diameters.

Actual studies of atomization variables concentrated on the sprays from simple cylindrical tube injectors. The variables studied and the approximate ranges covered were: relative velocity between air stream and liquid jet (V, 200 to 1000 ft./sec.), air density (ρ_A, .046 to 0.26 lb./ft.^{3}), injector inside diameter (D, 3/64, 3/32, and 3/16-inch), liquid injection velocity (v, 4 to 100 ft./sec.), liquid viscosity (μ_L, 3.3 to 11.3 centipoises), and mass median diameter (X, 19 to 118 microns). The results were summarized by the following proportion:

$$X \sim V^{-1.34} D^{0.16} v^{.08} \mu_L^{0.34} (1 + .05/\rho_A)$$

This can be written dimensionlessly by including three properties not varied significantly (air viscosity, μ_A, usually .023 centipoises; surface tension, σ_L, usually 22.0 dynes/cm.; and liquid density, ρ_L, usually 0.828 gram/cm.^{3}):

$$\left(\frac{X\rho_A V^2}{\sigma_L}\right) = 0.60\left(\frac{V\mu_L}{\sigma_L}\right)^{2/3}\left(1 + \frac{10^3\rho_A}{\rho_L}\right)\left(\frac{D\rho_L\sqrt{v\sigma_L\mu_A}}{\mu_L^2}\right)^{1/6}$$

For the 101 runs made with simple tubes, this equation (with all variables in consistent units) correlated observed median diameters with a standard deviation of about 10%; the errors were somewhat larger for the smallest injector at the lowest relative velocities. Injecting costream rather than contrastream had no effect on drop size at a given relative velocity.

Sprays from fixed orifice hydraulic nozzles, variable orifice hydraulic nozzles, and pneumatic nozzles were also studied. Properly designed pneumatic nozzles produced the smallest drops at all main duct air velocities. Variable area nozzles usually gave finer sprays than fixed area nozzles; of the latter, a small hollow cone design performed best. At low relative air velocities, the smallest median drop from a hydraulic nozzle was about half the diameter of drops from simple tubes. At high relative air velocities, only the pneumatic nozzles produced drops smaller than simple tube drops by as much as 15%.

The upper-limit equation (a modified log-probability equation which assumes a maximum drop size) was used to fit the entire drop size distribution for each run in this study. Differences between observed and equation-predicted volume percentages (at any diameter) averaged less than 4% in over 96% of the runs.

Microfilm $4.00; Xerox $13.95. 309 pages.

DA 21-3034

W-12. Weiss, M. A. and C. H. Worsham

2069. Weiss, M. A., and Worsham, C. H., Atomization in high velocity airstreams, *ARS J.* **29**, 4, 252-259, Apr. 1959.

An experimental study was made of the drop sizes obtained on injecting a liquid into large hot airstreams of sustained high velocity. The liquid, a molten synthetic wax, was injected contrastream or costream through simple cylindrical tubes. Downstream, a traversing probe withdrew a representative sample of the stream, cooled it and froze the droplets. The collected solid particles were analyzed by sedimentation and by sieving. The results were correlated empirically by the dimensionless equation

$$\frac{X\rho_A V^2}{\sigma_L} = 0.61\left(\frac{V\mu_L}{\sigma_L}\right)^{1/3}\left(1+\frac{10^3\rho_A}{\rho_L}\right)\left(\frac{W\rho_L\sigma_L\mu_A}{\mu_L^4}\right)^{1/12}$$

Mass median diameter (X), air density (ρ_A), relative velocity (V), liquid viscosity (μ_L) and mass injection rate (W) were changed over 4- to 25-fold ranges. Surface tension (σ_L), liquid density (ρ_L) and air viscosity (μ_A) were not changed significantly.

AMR 13-2069

W-13. Weiss, M. A. and C. H. Worsham

4290 Atomization in High Velocity Air Streams. An experimental study to simulate fuel injection in turbojet afterburners and in ramjets; a knowledge of the drop sizes obtained would help in the design of jet engines and their fuel systems. *Malcolm A. Weiss and Charles H. Worsham.* 347 pp. May 1958. Esso Research and Engineering Co., Linden, N. J. (TC173 Es79a Over.)

BMI 8-4290

W-14. Wenk, P.

"Aerosols." Siemens-Schuckertwerke Akt.-Ges. (Paul Wenk, inventor). Ger. 947,156, Aug. 9, 1956

CA 53-8478f

W-15. Wenk, P.

"Aerosols." Siemens-Schuckertwerke A.-G. (Paul Wenk, inventor). Ger. 936,868, Dec. 22, 1955

CA 52-16655e

W-16. Wetzel, R. H.

"Venturi Atomization" Univ. Wisconsin, Chem. Eng. Dept. Ph.D. Thesis, 1951

W-17. Wheeler, L. K. and E. S. Trickett

707 Measurement of the Size-Distribution of Spray Particles. L. K. Wheeler and E. S. Trickett. *Electrical Engineering,* v. 25, Oct. 1953, p. 402-406.

Describes apparatus and its operating characteristics. Photograph, diagrams, graph. 8 ref.

BMI 3-707

W-18. White, D. A. and J. A. Tallmadge

"Theory of Drag Out of Liquids on Flat Plates" Chem. Eng. Sci. 20, No. 1, 33-38 (Jan. 1965)

W-19. Widmer, F.

A65-16907
FORMATION OF DROPLETS AT A NOZZLE IN A PULSATING LIQUID [TROPFENBILDUNG AN EINER DÜSE IN EINER PULSIERENDEN FLÜSSIGKEIT].
F. Widmer (Eidgenössische Technische Hochschule, Institut für kalorische Apparate und Kältetechnik, Zurich, Switzerland).
Chemie-Ingenieur-Technik, vol. 37, Jan. 1965, p. 39-43. 6 refs. In German.
Research supported by the Schweizerische Eidgenossenschaft.

Determination of the size of droplets that, in the liquid phase, form at the nozzle and perforated plates of spray-type and sieve-type extraction columns. The formation of droplets at a nozzle in a pulsating liquid exhibits certain frequency ranges in which droplets of the same size detach regularly at each third, second, and first pulse. The transition regions between these ranges are characterized by irregular detachment, and the formation of nozzles of different size. For such a transition region, an equation containing two empirical quantities is derived which describes the relation between volume velocity and the corresponding fundamental frequency. The equation is shown to hold for a wide range of pulse amplitudes, nozzle diameters, and liquid systems.

A65-16907, 07-09

W-20. **Wieber, P. R. and W. R. Mickelsen**

Effect of Transverse Acoustic Oscillations on the Vaporization of a Liquid-Fuel Droplet. Paul R. Wieber and William R. Mickelsen (Lewis Res. Center, Cleveland, Ohio). NASA TN D-287, May 1960, 25 p., 9 fig., 18 ref.

Subject was investigated by theoretical analysis on an n-octane droplet. Three differential equations expressing the drop axial and transverse acceleration and vaporization rate were solved on an analog computer for a range of gas conditions, drop diameters from 10 to 500 microns, axial gas velocities from 0 to 800 ft/sec., and root-mean-square transverse particle velocities from 0 to 400 ft/sec. at frequencies of 200, 1000 and 4000 cps. Histories of the drop velocity, displacement, radius, and rate of change of radius with time were obtained. Large drops of the order of 500 microns may experience a reduction to almost one-sixth of the vaporization time with no acoustic field; this may explain in part the high combustion efficiency observed in resonating combustors that are initially inefficient.

deJ II-373

W-21. **Wigg, L. D.**

Drop Size Prediction for Twin-Fluid Atomizers. L. D. Wigg (Natl. Gas Turbine Establ., Great Brit.). NGTE Rep. M. 343, Sept. 1960, 11 p., 4 fig., 1 tabl., 9 ref.

Refers to WIGG 1959. Based on analysis of existing data on mean drop size of sprays produced by twin-fluid atomizers, a new parameter has been developed which takes into account all relevant variables: (1) kinematic viscosity (centistokes), (2) mass flow rates of liquid and of air, (3) surface tension, (4) air density, (5) relative velocity, (6) a characteristic linear dimension. This has been found valid for sprays in which no coalescence or recombination of droplets occurs, and makes possible the prediction of performance of twin-fluid atomizers, including carburetors. The mass median diameter (microns) is:

$$d = 190\, N\, (1 + 2.6 \left(\frac{W}{A}\right)^{0.6} W^{0.1}$$

in which "W" and "A" are the liquid and air mass flow rates (gm/sec.), and "N" is a parameter formed of a characteristic linear dimension, surface tension, density, and relative velocity.

deJ II-374

W-22. **Wigg, L. D.**

The Effect of Scale on Fine Sprays Produced by Large Air-Blast Atomizers. L. D. Wigg (Natl. Gas Turb. Establ., Gr. Brit.). NGTE Rep. R-236, July 1959, 15 p., 9 fig., 1 tabl., 12 ref.

Three Large air-blast atomizers have been tested which can handle water mass flows up to 1 lb/sec. (450 gm/sec.); these are identical in design but are scaled to give flow areas in the ratios 1:4:8. Reviews various analytical expressions for mean drop size. To compare the performance of different atomizers a parameter has been evolved by relating the loss of kinetic energy to the energy required to overcome the viscous forces involved in the rapid disintegration of the liquid film. This leads to an expression for the mass median diameter which is composed of the products of [illegible] of viscosity, mass flow rates of liquid and of air, and the relative velocity. This [illegible] when there is no coalescence or recombination of droplets. An empirical expr[illegible] mass median diameter is developed which applies to all three atomizers. Scale affects [illegible] mean drop size only through its influence on liquid mass flow rate. The expression shows that effect of mass flow rate is very great when there is recombination of droplets.

deJ II-374

W-23. **Wilcox, J. D.**

"Breakup of Liquid Droplets, Thickened and Unthickened" pp. 17-30 in "Spray Dissemination of Agents" Report of Symposium VIII, Vol. I. Conducted by U.S. Army, CWL March 4-6, 1958.

AD 205 196

W-24. **Wilcox, J. D. and R. K. June**

3898. Wilcox, J. D., and June, R. K., Apparatus for study of the breakup of liquid drops by high velocity airstreams, *J. Franklin Inst.* 271, 3, 169-183, Mar. 1961.

Article surveys previous investigations of high-velocity breakup of liquids, by Engel, Hansen and Domich, and Lane, and the breakup of drops and sprays by Priem. In present research, data in air flow in the range of Mach 1.0 were sought. Steady-flow air nozzle was considered unsuitable because an initially spherical drop cannot be formed within the jet. A suddenly applied air flow was needed and, to obtain this, two techniques were tried, (1) by blast gun and (2) by shock tube. The blast gun is a pressurized cylindrical chamber, separated from an open-ended expansion chamber by a frangible diaphragm. At high pressures, the bursting diaphragm allows a shock wave and an air blast to form within the expansion chamber and to form an air jet directed onto the externally located test object, in this case a liquid drop which was supported, without any cross hairs or filament, on an air-suspension column. Experiments showed this method unsatisfactory, owing to spurious action of jet vortex and unevenness of air flow.

The shock tube also has a frangible diaphragm between the pressurized chamber and the expansion chamber, but the end of the expansion chamber is closed, and the test area is enclosed within the shock tube. The flow in the shock tube was found to be uniform and adjustable, and the pressure behind the shock front could be closely regulated. The shock tube was set up vertically, and the drop was allowed to fall freely within the tube, and meet the shock wave. Shadowgraph pictures were obtained of the successive stages of disintegration of the drop, using a closely timed electric spark.

The experimental arrangements for both devices, the flash circuit and triggering circuit, and the operational procedure are described; photographs of the disintegrating drops provide evidence to support previous findings that the high-speed airstream strips off droplets from the surface of the large drop, deforms the drop in an interaction of the accelerating, inertia and surface tension forces, after which a chaotic disintegration of the bulk of the drop takes place. Present paper is primarily a description of the apparatus, and its capabilities and limitations. It is a clear exposition of the requirements, and means of attack, of research on high-speed liquid atomization, with its increasing importance for numerous fields of application.

AMR 14-3898

W-25. Wilcox, J. D., et al.

"The Effect of Polymeric Modifiers on the Breakup of Drops by High-Velocity Air Streams." J. D. Wilcox, R. K. June, H. A. Brown, Jr., and R. C. Kelley, Jr. (U.S. Army Chem. Warfare Labs., Army Chem. Center, Md). U.S. Dept Com., Office Tech. Serv., P B Rept. 144,740, 22 pp. (1959).

CA 56-5788i

W-26. Wilcox, R. L. and R. W. Tate

4491. Wilcox, R. L., and Tate, R. W., Liquid atomization in a high intensity sound field, *AIChE J.* 11, 1, 69-72, Jan. 1965.

Authors studied the performance of intense sound generators as atomizers, including Hartmann whistle, stem-and-cavity sound generator, and an elliptical reflector focussing sound at the atomization point. Emphasis was on highoutput (20-180 gallons of water/hr) and coarse droplet spectrum conditions (Sauter mean diameter of 21-600 microns).

Conclusion was that the production of [illegible] offered no advantage, in terms of the relation bet[illegible] and air/liquid ratio, over conventional two-flu[illegible] Reviewer is very much in accord with this result.

AMR 18-4491

W-27. Wilde, K. A.

6838. CONDENSATION IN NOZZLES. K.A.Wilde. J. appl. Phys., Vol. 30, No. 4(1), 577-80 (April, 1959).

The extent of realization of vapour—liquid phase equilibrium in nozzles was investigated as a function of initial particle size, kinetic parameters, and nozzle dimensions. It was shown that condensation will occur on already present particles only for very small sizes and/or large nozzles 20-30 in. or more in diameter. The present rather rudimentary state of knowledge of spontaneous nucleation does not enable any reliable evaluation of condensation by this mechanism.

PA 62-6838

W-28. Williams, F. A.

5300. Williams, F. A., Spray combustion and atomization, *Physics of Fluids* 1, 6, 541-545, Nov./Dec. 1958.

For the description of the complex disorder encountered in sprays a statistical approach is required. A description of the behavior of sprays is presented, which includes the effect of droplet growth, the formation of new droplets, collisions, and aerodynamic forces. Criteria for the efficiency of impinging jet atomization are developed. It is shown that, if the incident jets have a size distribution of a generalized Rosin-Rammler type, the resulting spray belongs to the same class of distributions. The size history of evaporating sprays is also obtained from the theory. A spray combustion analysis given by Probert is extended to include more general size distributions, the effect of droplet interactions, and the relative motion of the droplets and the fluid. It is shown that the overall spray evaporation rate is largest for uniform sprays.

This paper is an attempt at a unified spray theory, in a very condensed form, the value of which for the reader would be enhanced by more detailed explanations of the concepts used, and of the various mathematical operations.

AMR 12-5300

W-29. Williamson, K. I. and W. S. Taylor

"The Analysis of Particle Counts by the Spray-Drop Method" Brit. J. Appl. Phys. 9, 264-7 (July 1958)

W-30. Willits, C. O. and J. A. Connelly

"Atomizer for Flame Spectrophotometry." C. O. Willits and J. A. Connelly (Eastern Regional Research Lab., Philadelphia, Pa.). Anal. Chem. 24, 1525-6 (1952).

CA 47-1433i

W-31. Wilson, J. G.

"Note on Optical Methods of Measuring the Size of Small Water Drops" Proc. Comb. Phil. Soc. 32, 493-8 (1936)

W-32. Woeltjen, A.

Über die Feinheit der Brennstoffzerstäubung in Ölmaschinen (On the Fineness of Fuel Atomization in Oil Engines). A. Woeltjen. Diss., T. H. Darmstadt (Germ.) (1925). 54 p., 50 fig.

Photomicrographic method for the investigation of droplet sizes in sprays produced by air injection and solid injection. The oil is injected into a nonmiscible medium, a gelatinuous tanning extract (trade name "Quool"), and the suspended droplets are photographed and measured. The dependence of droplet sizes on injection pressure and air density is discussed and shown on graphs. Numerous photomicrographs of drops are reproduced.

deJ I-372

W-33. Wolf, H. F.

"Liquefied Gas Aerosols." Herbert F. Wolf (Coll. Sacred Heart, Santurce, P. R.). El Crisol (Puerto Rico) 4, No. 1, 4-15 (1950) (in English).

CA 44-10999f

W-34. Wolf, W. R.

15826 STUDY OF THE VIBRATING REED IN THE PRODUCTION OF SMALL DROPLETS AND SOLID PARTICLES OF UNIFORM SIZE. W.R.Wolf. Rev. sci. Instrum. (USA), Vol. 32, No. 10, 1124-9 (Oct., 1961).

The production of uniformly sized droplets of pure liquids, solutions, suspensions, and of solid particles in the size range of 4 to 200 μ in diameter employing the vibrating reed is described.

Salient features of the various devices are discussed where particular attention is devoted to the stability in size uniformity of the droplets or particles produced and their mechanism of formation. The methods described have found application in a variety of fundamental investigations, such as droplet evaporation and plant growth regulator studies, but their inherent low capacity makes them less suited for large-volume aerosols or sprays as are encountered, for example, in spray drying.

PA 64-15826

W-35. Wolfe, H. E. and W. H. Anderson

"Kinetics, Mechanism, and Resultant Droplet Sizes of the Aerodynamic Breakup of Liquid Jets" Aerojet-General Corp., Contract No. DA 18-108-405 CML 829, Report No. 0395-04(18)SP 275 pp., April 6, 1964

W-36. Woolridge, A.

"Techniques for Determination of Droplet Sizes in Spray" pp. 119-138 in "Spray Dissemination of Agents" Report of Symposium VIII, Vol. I. Conducted by U.S. Army, CWL, March 4-6, 1958.

AD 205 196

Y-1. Yaborskii, I. A.

4666. Yaborskii, I. A., The structure of the flow of a single jet in a system of plane jets (in Russian), *Izv. Sibirsk. Otd. Akad. Nauk SSR* no. 2, 62-74, 1958; *Ref. Zh. Mekh.* no. 2, 1959, Rev. 1350.

An analysis is carried out of the structure of a single jet and of a system of jets flowing from nozzles of rectangular section. The experimental data obtained by the author for the single jet are compared with Dymin's theoretical solution. It was found that the geometrical similarity of velocities in the transverse section of the jet was only maintained in nozzles with round outlet section and in rectangular nozzles with ratios of their sides $A/b > 30$. A jet emerging from the nozzles in other shapes assumed the form of a round jet at a comparatively short distance from the section of the nozzle. Empirical relations are drawn up for the axis velocity, mean velocity, consumption and boundaries of the jets, to deal with a system of plane-parallel jets. The question is worked out regarding the ejecting properties of a system of jets. It is found that if

$$\zeta > \left(\frac{F_o}{F}\right)^2 - 1$$

where ζ represents the sum total of the resistance (friction, eddying, etc.) of the flow of the jet system, F_o the total sectional area of the nozzles, F the area of the section of the mixing chamber, then there will be no suction of air into the chamber from the external medium.

AMR B-4666

Y-2. Yager, L. D.

7016 Atomizing Oil With High-Pressure Natural Gas. L. D. Yager. *Open Hearth Proceedings, American Institute of Mining and Metallurgical Engineers*, v. 35, 1952, p. 266-267.
Discusses effect on refractories and furnace efficiency.

BMI 2-7016

Y-3. Yeager, M. L., and C. L. Coffin

"A Survey of Components for Use with Air-Atomizing Oil-Burner Nozzles," American Petroleum Institute, API Publication 1720, Oct. 1961.

Y-4. Yeomans, A. H.

"A Method of Determining Particle Size of Liquified Gas Aerosols," USDA, Agri. Res. Serv., mimeo paper No. 33-5, 1955.

Y-5. Yeomans, A. H.

"Directions for Determining Particle Size of Aerosols and Fine Sprays," USDA Bur. Ent. and Plant Quar., ET-267, 7 pp., 1949.

Y-6. Yeomans, A. H.

"Field-model Aerosol Machines," U.S.D.A. Bur. Ent. and Plant Quar., ET-258, 8 pp., 1948.

Y-7. Yeomans, A. H., and W. G. Bodenstein

"An Exhaust Aerosol Generator for 1-1/2 Horsepower Motors," U.S.D.A. Bur. Ent. and Plant Quar., ET-238, 8 pp., 1947.

Y-8. Yeomans, A. H., and E. E. Rogers

6591* Factors Influencing Deposit of Spray Droplets. A. H. Yeomans and E. E. Rogers. *Journal of Economic Entomology*, v. 46, Feb. 1953, p. 57-60.
Describes characteristics of sprays applied with different kinds of atomizers.

BMI 2-6591

Y-9. York, J. L.

"Review of Instrumentation and Methods of Experimental Study of Sprays," Project SQUID Tech. Rep. NTI-1-C., 1953

Y-10. York, J. L., and H. E. Stubbs

Photographic Analysis of Sprays. J. L. York and H. E. Stubbs (Univ. of Mich.). Trans. ASME Vol. 74, No. 7 (Oct. 1952), pp. 1157–1162, 10 fig., 5 ref.

Experimental method for determining the size distribution and velocities of drops in spray. Flash photographs are taken of a small known volume of spray, and the images of drops are counted and measured. Velocities are determined by taking two exposures (at about 25 microseconds apart) on the same film and measuring the displacement of the drops in the interval between exposures. Apparatus and techniques are described; these are applicable to sprays in which the diameter of drops ranges from 15 to 500 microns; results differ by less than 20 per cent from the metered values of total flow rate.

deJ I-378

Y-11. York, J. L., and H. E. Stubbs

1442. York, J. L., and Stubbs, H. E., Photographic analysis of sprays, Ann. Meeting ASME, Atlantic City, Nov. 1951. Paper 51—A-48, 17 pp.

Problem, of interest in many fields, has attracted much attention in connection with gas turbines. Photography has been tried by other investigators but without much success in obtaining complete and accurate quantitative data. Authors take silhouette photographs of sections of the spray, using camera with open shutter and flash illumination (duration about 1 microsec). Photographs are projected, with 100 total magnification from droplet to screen, and are counted and measured, the depth of field being limited to that corresponding to known degree of blurring of photograph. Additional photographs of same sections of spray, using two flashes with known time interval, give information on velocities of droplets. Records of numbers, sizes, and velocities lead to graphs of drop-size distribution and calculations of mass flow per unit time. Authors give typical results for

Monarch Simplex nozzle spraying water at 200 lb per hr, the discrepancy between the flow rate calculated from the spray analysis and that obtained by direct measurement being less than 20%. Reviewer would have been interested to see more details, such as the number of photographs, the location of the sample fields, the number of droplets counted, and the time required for the whole process, in order to be better able to assess the usefulness and accuracy of the technique in relation to other methods.

AMR 5-1442

Y-12. York, J. L., H. E. Stubbs, and M. R. Tek

2524. York, J. L., Stubbs, H. E., and Tek, M. R., The mechanism of disintegration of liquid sheets, *Trans. ASME* **75, 7, 1279-1286, Oct. 1953.**

Authors study conditions at interface between two fluids, such as air and water, moving relative to one another. A disturbance on the surface of the liquid is acted upon by interfacial tension, tending to restore equilibrium, and by aerodynamic forces, tending to increase the magnitude of the disturbance. If the latter prevail, the interface will be unstable. Authors apply the conditions of potential flow to examine the pressures at the interface, and derive expressions for the rate of growth of disturbances on the surface of the liquid. They show how the rate of growth is affected by the wave length of the disturbance, the Weber number, the densities of the fluids, and the thickness of the liquid sheet. They apply the results to predict the conditions for maximum instability in a liquid sheet, leading to its rapid disintegration, and to estimate the size of droplets formed in the spray from a swirl-chamber atomizer. Comparison with photographs of sprays gives qualitative agreement.

AMR 7-2524

Y-13. Yurkstas, E. P., and C. J. Meisenzehl

N64-33069 Rochester U., N.Y. Radiation Chemistry and Toxicology Div.
SOLID HOMOGENEOUS AEROSOL PRODUCTION BY ELECTRICAL ATOMIZATION
Edward P. Yurkstas and Charles J. Meisenzehl 30 Oct. 1964 42p refs
(Contract W-7401-ENG-49)
(UR-652)

This report describes research into the generation of solid homogeneous aerosols from a source producing uniform, charged droplets from liquid solutions by electrical atomization. The process involves the ejection of the material from a capillary and its disruption in air or other gaseous medium by the application of an electrical field to the material. The development of the method together with the mechanism for uniform droplet and particle formation, the relationships involving the physiochemical properties of the source and the material to be ejected, along with consideration for stable and continuous production of the aerosol, are discussed.

N64-33069, 24-11

Y-14. Yutkin, L. A., and L. I. Gol'tsova

N64-22649 Air Force Systems Command, Wright-Patterson AFB, Ohio Foreign Technology Div.
ELECTROHYDRAULIC METHOD OF FEEDING AND ATOMIZING LIQUID FUELS AND OTHER LIQUIDS AND DEVICE FOR ITS ACCOMPLISHMENT
L. A. Yutkin and L. I. Gol'tsova 3 Jun. 1963 7 p Transl. into ENGLISH from Soviet Patent no. 119403, 20 Jan. 1951 p 1-3
(FTD-TT-63-478/1+2; AD-412975)

The proposed method of feeding and atomizing liquids and the device for this purpose are based on the complex action of a single electrohydraulic impact that occurs on dischargers in a volume of liquid inside a special device, which is used for supplying, atomizing, and pumping a new portion of the liquid. This device is in the form of a chamber, consisting of a hollow space and having one end closed by a movable piston. There is a channel at the inlet to the chamber; this channel is bent in the form of many elbows through which liquid is fed into the chamber. The purpose of the channel is to buffer the shock impulse that is traveling in the direction of the feeding reservoir. Through an analogously designed channel, the liquid constantly flows out of the chamber. A long nozzle for ejecting the liquid is located at the other end of the chamber.

N64-22649, 15-07

Z-1. Zagar, L.

Über die Kennzeichnung diskret disperser Systeme (Characteristics of discrete disperse Systems). L. Zagar (Inst. anorg. und phys. Chemie, Techn. Hochsch. Graz, Austria). Koll.-Z. Vol. 130, No. 1 (1953), pp. 1–10, 6 fig., 29 ref.

The shape and position of the grain-size distribution curve of a discrete disperse system is defined by the statistical parameters d_g (geometric-median grain size) and σ_g (the geometric scatter). With these data are defined also the significant physical characteristics of the system: S the specific surface, N the number of particles pro gram of dispersoid, the size Δ of the particle having the median surface, and D the size of particle having the median volume and weight. This functional interrelationship can be utilized fully only if the characteristic constants valid for the grain shape of every powder type are first determined. These are: the surface factor α, the volume factor β, and the shape factor γ. According to the theoretical treatment given in the paper granulometric analyses have been carried out on 23 metal powders. The number of particles in one gram is determined by the counting chamber method; specific volume is determined by air-permeability measurement. From these the shape factors are calculated, using carbonyl powder as testing standard. Gives a thorough theoretical background; it deals primarily with solid particles, but its method and findings are applicable also to droplet populations.

deJ I-381

Z-2. Zawidzki, T. W., et al

"Vonnegut's Spraying Fountain, An Oxygen-Pressure Dependent Chemical Process." Tadeusz W. Zawidzki, Gianna L. Petriconi, and Henry M. Papee (Centro Nucl. Aerosoli, Rome). Z. Angew. Math. Phys. 14, 441-8 (1963)

CA 60-2337g

Z-3. Zeleny, J.

The Role of Surface Instability in Electrical Discharges from Drops of Alcohol and Water in Air at Atmospheric Pressure. John Zeleny (Yale Univ., New Haven, Conn.). Jl. Franklin Inst., Vol. 219, June 1935, pp. 659–675, 3 fig., 16 ref. (no titl.).

Refers to RAYLEIGH 1882 A. Previous experiments on discharges from charged attached drops, from uncharged drops, and from uncharged drops falling in electric fields, shows that the surface-electrical intensities at these drops, when the discharges begin, satisfy the theoretical relations for surface instability. Glow discharges, if initially present, are conditioned by the surface deformation arising from instability. Describes experiments showing that highly charged droplets ejected by an alcohol surface may have mobilities not much below those of normal air ions, while droplets coming from a water surface may have mobilities even greater than those of air ions. Calculations, by Stokes' law, show that large mobilities for both kinds of drops are possible. Further experiments show that under certain conditions the entire discharge current from an alcohol drop is carried solely by droplets of the liquid resulting from surface instability; under more restricted conditions the same may be true for a water drop. Shows water jets emerging from nozzles under various electrical conditions.

deJ II-384

Z-4. Ziabicki, A., and R. Takserman-Krozer

"Formation and Breakage of Liquid Threads, I. Mechanism." Roczniki Chem. 37, No. 11, 1503-9 (1963)

Z-5. Ziabicki, A., and R. Takserman-Krozer

"Formation and Breakage of Liquid Threads. II. Cohesive Break of a Steady Liquid Jet," Roczniki Chem. 37, 1511-18 (1963).

Z-6. Ziabicki, A., and R. Takserman-Krozer

"Formation and Breakage of Liquid Threads. III. Capillary Break-up of a Steady Viscous Jet." Andrzej Ziabicki and Rachela Takserman-Krozer (Inst. Chem. Ogolnej, Warsaw). Roczniki Chem. 37(12), 1607-16 (1963) (in English)

CA 60-15173f

Z-7. Zuev, V. E., et al.

A65-27616 #
ATTENUATION OF VISIBLE AND INFRARED RADIATION BY ARTIFICIAL WATER FOGS [OSLABLENIE VIDIMOI I INFRAKRASNOI RADIATSII VODNYMI ISKUSSTVENNYMI TUMANAMI].
V. E. Zuev, B. P. Koshelev, S. D. Tvorogov, and S. S. Khmelevtsov (Sibirskii Fiziko-Tekhnicheskii Institut, Tomsk, USSR). Akademiia Nauk SSSR, Izvestiia, Fizika Atmosfery i Okeana, vol. 1, May 1965, p. 509-516. 9 refs. In Russian.

Results of a theoretical and experimental study of the optical and microphysical properties of artificial aqueous fogs as attenuating factors for visible and IR radiation. An approximate method for determining attenuation factors is proposed and assessed. The method used in studying fog microstructure and translucence is described. In the visible spectral band, the attenuation factor is found to be practically independent of the wavelength. Fog attenuation factor variations across the 1- to 14-μ spectral band strongly depend on fog droplet microstructure, increasing with droplet-distribution half-width and the reciprocal of the radius of the most probable distribution of droplet size. Theoretical and experimental results are compared.

A65-27616, 17-20

[redacted]

C. Supplementary Survey

Open Literature and Government Report Literature References for Period of September 1965 through December 1966

1. Barretto, E. and M. J. Mulcahy

19697 PRODUCTION AND NEUTRALIZATION OF A CHARGED AEROSOL BY CORONA FIELDS.
E. Barreto and M. J. Mulcahy.
J. Geophys Res. (USA). Vol. 70, No. 6, 1303-10 (15 March 1965).
The condensation of one the components in a gas flow mixture is shown to increase significantly the amount of current blown past a negative point-ring corona discharge. Using a nozzle configuration, the power required to form and charge the aerosol can be shown to originate from the mechanical energy of the flow and not from the power supply feeding the corona discharge. At constant velocity and pressure the amount of current available from the point is not affected by gas composition and does not vary significantly with particle size if a minimum size is exceeded. The highly charged aerosol cloud has a space charge density such that it invokes a positive corona discharge from a grounded point in its vicinity. This discharge effectively neutralizes the cloud charge. In consequence, this method indicates attractive possibilities for experimentation in the production and interaction of positively and negatively charged miniature cloud masses and electrical discharges between them.

PA68-19697

2. Bejan, I., C. Ungureanu, et. al.

"Study of Uniformity of Atomization by Rotating Injectors" (in Roumanian)
Bul. Sti. Tehn. Inst. Politehn. Timisoara 9, No. 1, 57-64 (1964).

3. Beltran, M. R. et. al

AD-487 242 Fld. 21/8.1, 21/9.1
DYNAMIC SCIENCE CORP MONROVIA CALIF
LIQUID ROCKET ENGINE COMBUSTION INSTABILITY STUDIES.
Final rept. 1 Jan 65-31 Mar 66,
by M. R. Beltran, B. P. Breen, T. C. Kosvic, C. F. Sanders, and R. J. Hoffman. 1 Jul 66, 137p.
Rept. no. SN-68-F
Contract AF 04(611)-10542 Proj. AF-3505
Task 04
AFRPL TR-66-125

Unclassified report

Distribution: No Foreign without approval of Air Force Rocket Propulsion Lab., Edwards, Calif. 93523.

Descriptors: (*Rocket motors (Liquid propellant), Combustion), Stability, Burning rate, Drops, Particle size, Distribution, Injection, Velocity, Combustion chambers, Pressure, Mixtures, Methyl hydrazines, Nitrogen compounds, Tetroxides, Vaporization, Injectors, Fuel injectors, Ignition, Atomization, Scale, Liquid rocket propellants, Thixotropic rocket propellants, Hypergolic rocket propellants, Chemical reactions, Energy

Various combustion problems related to high frequency instability in liquid rocket engines were studied. Using the steady-state and instability computer programs developed under this study, a parametric investigation was conducted. This investigation determined the influence of droplet radius, droplet distribution, injection velocity, chamber pressure, and mixture ratio on the minimum threshold disturbance required to trigger combustion instability in a Transtage type engine configuration. The propellant combination considered was monomethylhydrazine/nitrogen tetroxide. Results of the study show that increases in injection velocity and droplet distribution increased stability. An increase in chamber pressure, based on constant flow rate increased stability while increases in chamber pressure, at a constant contraction ratio, decreased stability. There appears to be a droplet size for minimum stability, with changes in either direction resulting in improved stability. Results also show that due to the vapor phase reactions, monomethylhydrazine/nitrogen tetroxide vaporize at approximately the same rate. Thus, the oxidizer or fuel could be made to control the combustion process by slight changes in the injector and engine parameters. For the engine configuration studied the oxidizer vaporized slower than the fuel.

TAB 66-18

4. Bond, W. N.

524. Bubbles and Drops and Stokes' Law. W. N. Bond. *Phil. Mag.* 4. *pp.* 889–898, *Nov.*, 1927.
This paper extends Stokes' calculations for the slow rectilinear motion of a solid sphere through a viscous fluid to the case where the sphere is composed of fluid. Experiments on the rate of rise of air bubbles in water-glass and in golden syrup, and on the velocity of the fluid in the neighbourhood of the bubbles in the former liquid, are in substantial agreement with the prediction that the bubble should rise 1½ times as fast as it would if it were solid. Observations on air bubbles and drops of syrup in castor oil also show reasonable agreement with theory. The measured velocities of the fluid near steel spheres give a reasonably good check on Ladenburg's correction for the effect of the walls of the containing vessel. An addendum gives a correction for circulation of liquid inside the drop.

PA31-524

5. Bond, W. N. and D. A. Newton

2556. Bubbles, Drops and Stokes Law. W. N. Bond and D. A. Newton. *Phil. Mag.* 5. *pp.* 794–800, *April*, 1928.
In a previous paper [see Abstract 524 (1928)] it was shown that drops or bubbles in a more viscous medium might have a terminal velocity of one and a half times that of a solid sphere. The present paper shows experimentally and theoretically that surface tension of the drop or bubble decreases the terminal velocity. For radii less than a critical value the drop behaves as a rigid sphere. After a fairly rapid transition through the critical point the effect of surface tension becomes small.

PA31-2556

6. Borodin, V. A., Yu. F. Dityakin, and V. I. Yagodkin

"On Mechanisms of Disintegration of Drops in a Gas Flow," Zh. Prikl. Mekh. Tekh. Fiz No. 3, 100-104 (1964).

7. Clark, B. J.

5831. **Clark, B. J., Breakup of a liquid jet in a transfer of gas,** NASA TN D-2424, 46 pp., Aug. 1964.

Research concerns the mechanism of breakup of liquid jet in a cross flow of gas. By an order-of-magnitude analysis of the momentum equation for the liquid, it is shown that dynamic pressure normal to the jet surface constitutes the controlling influence to the distortion of the jet cross section. Gravity and viscosity are not of importance. The surface tension tends initially to resist distortion, but, in the later stages of breakup, it actually assists in the process of disintegration. The proposed model holds for large Weber numbers and, under this condition, the degree of breakup can be correlated by a dimensionless parameter, ε, which is the ratio of the maximum displacement of the liquid in its distorted cross section to the original jet diameter.

A photographic study reveals that the jet progressively spreads and that drops and ligaments tear off along its edges. Oscillogram records show that the electrical resistance along the length of the jet has rather high frequency fluctuations. However, its temporal average appears to provide a good measure of the jet breakup. The correlation between ε and the degree of jet breakup is based on such electrical measurements.

AMR18-5831

8. Crowley, J. M.

32576 GROWTH AND EXCITATION OF ELECTROHYDRODYNAMIC SURFACE WAVES. J. M. Crowley. Phys. of Fluids (USA), Vol. 8, No. 9, 1668-75 (Sept. 1965).

Waves on the surface of a capillary liquid jet stressed by a steady applied electric field will grow in space if the velocity of the jet is supercapillary. Experimental measurements of this growth rate confirm previous theoretical discussions. The excitation of these waves by means of an applied electric field with steady and time varying components is also studied theoretically, and the frequency response is found to depend on both the shape of the electrodes and on the convective growth of the waves due to the steady component of the field. The predictions of this theory are confirmed by measurements on a water jet.

PA68-32576

9. Damon, K. G. et. al.

"A Simple Technique for Photographing Liquid Drops," Chem. Eng. Sci. 21, 813 (1966).

10. Davis, M. H.

A65-36625

THE EFFECT OF ELECTRIC CHARGES AND FIELDS ON THE COLLISIONS OF VERY SMALL CLOUD DROPS.

M. H. Davis (RAND Corp., Santa Monica, Calif.).

IN: INTERNATIONAL CONFERENCE ON CLOUD PHYSICS, TOKYO AND SAPPORO, JAPAN, MAY 24-JUNE 1, 1965, PROCEEDINGS. [A65-36603 24-20]

Conference sponsored by the International Association of Meteorology and Atmospheric Physics of the International Union of Geodesy and Geophysics, World Meteorological Organization, Science Council of Japan, and the Meteorological Society of Japan. Tokyo, Meteorological Society of Japan, 1965, p. 118-120. 7 refs.

Discussion of the influence of electric charges and fields on collisions of small cloud droplets using accurate electrostatic forces (Davis, 1962, 1964) and recently improved values for hydrodynamic forces. Of primary interest are cases when collisions will occur only under the influence of electrostatic forces (Sartor, 1960). The results are based on the numerical integration of droplet trajectories. Using Hocking's hydrodynamics it was estimated that electrostatic forces began to produce collisions in droplets with radii under 15μ under certain conditions. The effect was most important when the droplets were nearly the same size.

A65-36625, 24-20

11. Debeauvais, F.

3327. **Debeauvais, F., Disintegration of liquid jets in air stream** (in French), Minist. Air, Publ. Sci. Tech. France no. 406, 85 pp., 1964.

Paper presents a long, detailed account of a conventional approach to the study of jet disintegration by high speed photography. The photographs are good but reveal nothing new [see Green and Lane, Particulate Clouds, 1964, Spon, London]. The theoretical discussion is based on familiar equations and formulas. Interesting feature of paper is the attempt to provide a physical interpretation of the empirical Nukiyama-Tanasawa equation relating a mean droplet diameter to the aerodynamic parameters and physical properties of the liquid. This could be most usefully developed further.

Useful discussion is given of the optical problems in the photographic method of determining droplet size.

AMR18-3327

12. Debeauvais, F. and P. Vernotte

N66-14485# France. Ministere de l'Air, Paris.
CONTRIBUTION TO THE STUDY OF LIQUID ATOMIZATION IN MOVING AIR [CONTRIBUTION A L'ETUDE DE LA DESAGREGATION DES JETS LIQUIDES DANS L'AIR EN MOUVEMENT]
Francis Debeauvais and Pierre Vernotte Serv. de Doc. Sci. et Tech. de l'Armenent, 1964 92 p refs In FRENCH *Its* Publ. Sci. et Tech. No. 406 CFSTI: HC $3.00/MF $0.75

Two methods of liquid atomization in air currents were studied: suction, which produces a uniform velocity field, and expulsion which produces a varying field. Experiments were conducted with water and dibutyle phtalate, and microphotography and high speed cinematography techniques were used in determining the droplet dimensions and their spatial distribution. The duration of the atomization process was calculated as a function of the liquid flow and air current velocities. Surface tension and viscosity effects were determined and were shown to be negligible over a large interval. Theoretical calculations agreed with the quantitative results of the experiments.

N66-14485, 05-12

13. DeJuhasz, K. J.

1275. **Book—DeJuhasz, K. J., compiled and edited by, Spray literature abstracts, Vol. II,** published by author: Prof. K. J. DeJuhasz, 423 West Park Avenue, State College, Penn. and with support of U. S. Dept. of Health, Education, and Welfare, 1964, vii + 384 pp. $15.00.

Author up-dates previous Volume I [AMR 13(1960), Rev. 1515], which covered the period 1880 to 1958, inclusive. Present Volume II comprises about 1200 items published between 1959 and the end of 1961, plus some earlier literature which was not included in the first volume.

Entries contain full bibliographic data and abstracts of items dealing with all aspects of sprays. Specific topics covered are fuel sprays for furnaces, internal combustion engines, gas turbines, and rockets; sprays for industrial processes involving evaporation, humidification, cooling, air conditioning, and chemical reactions; atmospheric sprays such as rain, fog, sleet, and snow; agricultural sprays; fire fighting sprays including sprinkler systems; aerosols for medical applications; dusts and powders, especially particle size measurement; and sprays for military defense and offense. Basic and applied science literature relating to the theoretical and experimental study of sprays are also abstracted. Included are the broad fields of mathematics, physics, chemistry, thermodynamics and mechanical engineering as they relate to many aspects of spray formation, behavior and analysis.

No critical evaluation is attempted, but each reference is well abstracted, thereby providing excellent coverage of the literature of sprays and related topics for all who wish to undertake research or engineering in this broad field.

AMR18-1275

14. Dobbins, R. A., et. al.

"Further Studies on the Light Scattering Technique for Determination of Size Distributions in Burning Sprays - I" Princeton Univ., Contract No. AF 18(600)-1527, AEC Report No. 463, April 10, 1959

15. Dolinskii, A. A. and L. M. Mishnaevskii

A66-26489 #
DETERMINATION OF THE DEGREE OF DISPERSION OF ATOMIZED LIQUIDS [OB OPREDELENII DISPERSNOSTI RASPYLA ZHIDKOSTI].
A. A. Dolinskii and L. M. Mishnaevskii.
IN: FLOWS OF FLUIDS AND GASES [TECHENIIA ZHIDKOSTEI I GAZOV].
Edited by V. I. Tolubinskii and V. A. Fedoseev.
Kiev, Izdatel'stvo Naukova Dumka, 1965, p. 51-55. 5 refs. In Russian.

Description of a method for determining the mean droplet size and the dispersion of atomized liquids in industrial air. Mineral oil thinly spread over microscope slides coated with a film of adhesive was used to trap the droplets. The mean surface area and volume of the absorbed droplets and the dispersion were determined from photomicrographs. Curves for the dispersion density are plotted. The accuracy of the measurements was ± 5%.

A66-26489, 13-12

16. Fisher, R. A. and E. A. Rojec

AD-487 523 Fld. 21/8.1
ROCKETDYNE CANOGA PARK CALIF
STUDY OF DROPLET EFFECTS ON STEADY-STATE COMBUSTION. VOLUME II: DROPLET SIZE DISTRIBUTION MEASUREMENTS WITH THE ELECTROMETER PROBE TECHNIQUE.
Final rept. 1 Jul 65-1 Apr 66,
by R. A. Fisher, and E. A. Rojec. Aug 66, 95p.
Rept. no. R-6543-2
Contract AF 04(611)-10825 Proj. AF-3058
AFRPL TR-66-152-Vol-2
Unclassified report

See also Volume I, AD-487 522.

Distribution: No Foreign without approval of Air Force Rocket Propulsion Lab., Edwards, Calif. 93523. Attn: RPPR/STINFO.

Descriptors: (*Injectors, Drops), (*Rocket motors (Liquid propellant), Injectors), (*Fuel injectors, Rocket motors (Liquid propellant)), Particle size, Distribution, Combustion, Probes (Electromagnetic), Electrometers, Water injection, Water impingement, Sprays, Pulse height analyzers, Signal generators, Calibration, Measurement, Experimental data

The drop size measurement technique is discussed and the results of this effort are presented. An electronic probe was built and calibrated for the purpose of measuring drop size distribution in liquid spray. It was then used successfully to measure such distributions for water sprays produced by a series of injectors.

TAB-66-19

17. Fisher, R. A., E. A. Rojec, et. al.

...487 522 Fld. 21/8.1
...ETDYNE CANOGA PARK CALIF
ST... OF DROPLET EFFECTS ON STEADY-STATE COMBUSTION. VOLUME I: MEASURED SPRAY PARAMETER ANALYSIS AND PERFORMANCE CORRELATION.
Final rept. 1 Jul 65-31 Mar 66,
by R. A. Fisher, E. A. Rojec, H. E. Otte, S. D. Clapp, and G. L. Falkenstein. Aug 66, 87p.
Rept. no. R-6543-1
Contract AF 04(611)-10825 Proj. AF-3058
...RPL TR-66-152-Vol-1
Unclassified report

See Volume 2, AD-487 523.

Distribution: No Foreign without approval of Air Force Rocket Propulsion Lab., Edwards, Calif. 93523. Attn: RPPRISTINFO.

Descriptors: (*Injectors, Rocket motors (Liquid propellant)), (*Fuel injectors, Rocket motors (Liquid propellant)), Combustion, Fuel injection, Performance (Engineering), Drops, Spray nozzles, Fuel sprays, Cold flow tests, Orifices, Oxidizers, Momentum, Particle size

The effects of injector-induced mass, mixture ratio and droplet distribution characteristics on steady-state combustion performance are studied. The program included both analytical and experimental efforts to show correlation between injector design and combustion efficiency using spray parameter measurements. The effects of measured spray parameters on the combustion performance were established by analytical methods for the injectors investigated. Mixture ratio distribution was observed to have a significant effect on performance, as was the injector orifice parameters, the square root of the ratio of orifice diameter to velocity. The mass distribution, as defined, did not produce an entirely consistent effect over the range of variation studied. Data are presented for various impinging orifice injector types and propellant combinations, and the importance of data segregation in terms of such factors as injector type, propellant combinations, and spray measurement techniques to ensure proper interpretation is discussed.

TAB66-19

18. Fogler, H. S. and K. D. Timmerhaus

8163. Fogler, H. S., and Timmerhaus, K. D., Ultrasonic atomization studies, *J. Acoust. Soc. Amer.* **39**, 3, 515-518, Mar. 1966.

Atomization of selected fluids has been observed to occur in a capillary at various resonance heights of the standing ultrasonic wave in the fluid. The length of fogging has been observed to be a function of the voltage applied to the transducer producing the ultrasonic wave in the fluid. A theoretical analysis is given to explain the experimental results obtained.

AMR19-8163

19. Fujiwara, M.

A65-36631 #
A PROPOSED FORMULA OF RAINDROP SIZE DISTRIBUTION.
Miyuki Fujiwara (Tokyo, University, Meteorological Research Institute, Tokyo, Japan).
IN: INTERNATIONAL CONFERENCE ON CLOUD PHYSICS, TOKYO AND SAPPORO, JAPAN, MAY 24-JUNE 1, 1965, PROCEEDINGS. [A65-36603 24-20]
Conference sponsored by the International Association of Meteorology and Atmospheric Physics of the International Union of Geodesy and Geophysics, World Meteorological Organization, Science Council of Japan, and the Meteorological Society of Japan.
Tokyo, Meteorological Society of Japan, 1965, p. 265-270. 10 refs.

Discussion of a flexible equation that takes into account variations in the parameters of raindrop size distribution such as spectrum width, mode size, skewness, and total concentration. Examples are presented to show that the proposed equation gives a better fit than that of Marshall and Palmer for the instantaneous sampling of data in the case of moderate rains. The physical meaning of the fitting equation is explained, and the concepts of coalescence and accretion are defined. Coalescence is termed as a process between precipitable drops, while accretion is a process between precipitable drops and cloud droplets; therefore, coalescence decreases the total number of precipitable drops as the process advances, while accretion does not.

A65-36631, 24-20

20. Gan'kovskii, B. D.

36917 CHARACTERISTICS OF AN INSTRUMENT FOR MEASURING THE SIZE OF FOG DROPS AND AEROSOL PARTICLES. B. D. Gan'kovskii.
Zh. Priklad. Spektrosk. (USSR), Vol. 5, No. 2, 221-7 (Aug. 1966).
In Russian.

A photometric solution is found to the problem of size determination of fog-drops and solid particles of aerosols. The value of possible errors of the instrument is given.

PA69-36917

21. Gardiner, J. A.

"Measurement of the Drop Size Distribution in Water Sprays by an Electrical Method" Instrument Practice 18, No. 4, 353-6 (April 1964).

22. Giraudi-Industria Elettromeccanica S.r.l.

"Metal Power Spray Gun," Italian Patent No. 658,464

CA63-12705e

23. Goldschmidt, V. W.

1697 MEASUREMENT OF AEROSOL CONCENTRATIONS WITH A HOT WIRE ANEMOMETER. V. W. Goldschmidt. J. Colloid Sci. (USA), Vol. 20, No. 6, 617-34 (Aug. 1965).

The use of a hot wire anemometer to measure local mean aerosol concentrations in turbulent flows is discussed. The instrument allows measurement of point particle concentration flux in turbulent shear flows. The extension of the instrument as a size distribution sampler and as a device to determine the kinematics of suspensions is suggested. Experimental calibration results are presented.

PA69-1697

24. Golovin, A. M.

1277. Golovin, A. M., The theory of the vibration and breakdown of droplets in a gas stream in the presence of rotational motion inside the droplets: Part 1, *Bull., Acad. Sci., USSR, Ser. Geophys.* no. 7, 658-662, July 1964.

The paper is devoted to analytical calculation of critical radius of a drop falling in an air stream. It is an elaboration of V. G. Levich's ["Physical-Chemical Hydrodynamics," Fitzmatgiz, 1959] hypothesis that the drop size is determined by two opposite forces: capillary forces that hold the drop together and dynamic pressure generated by the vorticity of the liquid in the drop. Introduction of liquid movement within the drop is not an entirely new idea. Baron ["Atomization of Liquid Jets and Droplets," Tech. Rep. no. 4, Eng. Exp. Station, Univ. of Illinois, 1947] theorized that an accelerated drop in air oscillates and rotates. Centrifugal forces cause the liquid to move to the drop periphery thinning the center. Critical radius for a free falling water drop is calculated to be about 0.20 cm. This agrees with observations that the radius of rain drops rarely exceeds 0.25 cm.

AMR19-1277

25. Golovin, A. M.

1278. Golovin, A. M., On the theory of oscillations and fractioning of a drop in a gas stream with a potential movement within the drop: Part 2, *Bull., Acad. Sci., USSR, Ser. Geophys.* no. 8, 769-771, 1964.

A system of equations determining the characteristic axisymmetrical oscillations of a spherical drop is examined. Calculations of the minimum value of Weber number for a drop moving with a uniform speed leads practically to the same results as in Part 1 [see preceding review]. Critical Weber numbers calculated by the author range from 2.16 to 6, depending on the mathematical description of perturbances. They are on the low side of previously reported work by several authors who place the critical Weber numbers in the range 6-22.

AMR19-1278

26. Goren, S. C. and S. Wronski

27081 THE SHAPE OF LOW-SPEED CAPILLARY JETS OF NEWTONIAN LIQUIDS. S. L. Goren and S. Wronski. J. Fluid Mech. (GB), Vol. 25, Pt 1, 185-98 (May 1966).

The shape of a jet of Newtonian liquid issuing from a capillary needle into air is considered. The results of two theoretical approaches are presented. One appraoch is a perturbation analysis about the final state of the jet and the other is a boundary-layer analysis near the point of jet formation. Comparison of the predictions with experimental jet shapes shows them to be in semi-quantitative agreement. Especially interesting is the presence of a "discontinuity" in the empirical exponential decay rate of the jet radius occurring at a Reynolds number somewhere between 14 and 20 and the correspondence of this discontinuity with the peculiar behaviour in this range of the Reynolds number of the theoretical eigenvalue.

PA69-27081

27. Hendricks, C. D.

A65-29763 *
COLLOID PROPULSION - STATE OF THE ART AND REVIEW OF CURRENT RESEARCH.
Charles D. Hendricks (Illinois, University, Dept. of Electrical Engineering, Urbana, Ill.).
USAF, Office of Scientific Research and United Aircraft Corp., Symposium on Advanced Propulsion Concepts, 4th, Palo Alto, Calif., Apr. 26-28, 1965, Paper. 16 p. 14 refs.
Grant No. AF AFOSR 107-64; Contract No. AF 33(615)-1459.

Survey of developments in the colloid scheme of electric propulsion. Characteristics which a heavy-particle system must have if it is to be competitive with cesium-tungsten and oscillating-electron thrustors include a narrow specific-charge distribution, a reliable source capable of operating unattended for long periods of time, and a very small beam divergence. Possible methods of producing charged heavy particles include particle condensation from vapor and subsequent charging, charged-particle production directly from ionized vapor by condensation, electrical spraying from extended knife-edge systems, and electrical spraying from hollow capillaries.

A65-29763, 18-28

28. Hidy, G. M.

A65-36620 *
MODELING GROWTH PROCESSES FOR PARTICLES IN CLOUDS.
G. M. Hidy (National Center for Atmospheric Research, Boulder, Colo.).
IN: INTERNATIONAL CONFERENCE ON CLOUD PHYSICS, TOKYO AND SAPPORO, JAPAN, MAY 24-JUNE 1, 1965, PROCEEDINGS. [A65-36603 24-20]
Conference sponsored by the International Association of Meteorology and Atmospheric Physics of the International Union of Geodesy and Geophysics, World Meteorological Organization, Science Council of Japan, and the Meteorological Society of Japan. Tokyo, Meteorological Society of Japan, 1965, p. 92-96. 12 refs.
NSF-supported research.

Discussion of examples of limiting models for the collision and coagulation of particles of aerosol clouds. The net influence of the collisional mechanisms on the size spectrum of aerosols is examined, assuming that the processes are approximately additive and each mechanism can be treated separately. Calculations were made for several limiting cases. The numerical results showed that the total number of particles per unit volume per unit time, N_∞, increased linearly with time over a substantial range for three cases.

even for initially nonuniform distributions. However, the linear dependence of N_∞^{-1} on time, which is well known for monodisperse aerosols coagulating by Brownian motion, was not found for the shear model. In fact, N_∞^{-1} was observed in one case to vary logarithmically with time as predicted by Swift and Friedlander. Features indicated by the size spectra calculated by this technique are described. It is noted that the use of the discrete model described for calculating spectra over a broad range of size proved to be rather limited.

A65-36620, 24-20

29. Hines, R. L.

27080 ELECTROSTATIC ATOMIZATION AND SPRAY PAINTING. R. L. Hines.
J. Appl. Phys. (USA), Vol. 37, No. 7, 2730-5 (June 1966).

The phenomenon of electrostatic atomization and the process of electrostatic spray painting are analyzed to show the role of the various physical parameters. The charging and atomization of an individual fluid jet in an electrostatic field are investigated in detail. Experimental data are presented for various quantities such as drop size and charge per unit mass of drops under typical conditions of electrostatic painting and also for single jets. Approximate formulas are given which relate these quantities to the fluid properties and the electrical fields in the system.

PA69-27080

30. Hunter, R. E. and S. H. Wineland

A65-34471
CHARGED COLLOID GENERATION RESEARCH.
R. E. Hunter and S. H. Wineland (USAF, Systems Command, Research and Technology Div., Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio).
IN: SPACE ELECTRONICS SYMPOSIUM; PROCEEDINGS OF THE JOINT AMERICAN ASTRONAUTICAL SOCIETY AND AEROSPACE ELECTRICAL SOCIETY MEETING, LOS ANGELES, CALIF., MAY 25-27, 1965. [A65-34466 22-07]
Edited by C. M. Wong.
New York, American Astronautical Society, 1965, p. II-1 to II-16. 9 refs.

Generation of charged particles by electrostatic spraying of liquids from capillary tubes as a method of obtaining a charging energy per unit expellant mass which is substantially less than that experienced with conventional ion sources. This capability will lead directly to efficient thrustor operation in the 2000- to 5000-sec specific-impulse range. The results of some of the research performed at the AF Aero Propulsion Laboratory which has contributed to the present level of understanding are presented. A combined time-of-flight/electric quadrupole spectrometer has been developed to provide a correlation of the two types of measurement of specific charge distribution. Very good agreement between the two techniques has been achieved. Different expellants have been tried, and the best results to date have been achieved with glycerine doped to about 1500 ohm-cm at 30°C with sodium iodide. Several capillary needle configurations have been tried. The best results have been obtained with mechanically polished 4 mil I.D., 8 mil O.D. stainless steel needles. Specific charges (peaks) of several thousand coulombs/kg at distribution efficiencies above 75% are routinely achieved.

A65-34471, 22-28

31. Il'yashenko, S. M. and A. V. Talantov

AD-637 446 Fld. 21/2
CFSTI Prices: HC $6.00 MF $1.50
FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OHIO
THEORY AND ANALYSIS OF STRAIGHT-THROUGH-FLOW COMBUSTION CHAMBERS,
by S. M. Il'yashenko, and A. V. Talantov. 7 Apr 66, 295p. Rept. no. FTD-MT-63-143,
TT 66 62119

Unclassified report

Edited machine trans. of mono. Teoriya i Raschet Pryamotochnykh Kamer Sgoraniya, Moscow, 1964 306p.

Descriptors: (*Combustion chambers, *Combustion), Atomization, Fuels, Ballistics, Drops, Evaporation, Turbulence, Flames Stabilization, Mixtures, USSR

Contents: Discharge and atomization of liquid fuel; Ballistics of nonvaporizing drops; Evaporation of drops; Calculation of fields of concentrations of a fuel-air mixture; The theory of turbulent combustion of a homogenous mixture; Experimental investigations of burning in a turbulent flow of homogeneous mixture; Position of the flame in the combustion chamber; Flame stabilization; Burning of two-phase mixtures.

TAB66-20

32. Ingebo, R. D.

N66-30181*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.
ATOMIZATION OF ETHANOL JETS IN A COMBUSTOR WITH OSCILLATORY COMBUSTION-GAS FLOW
Robert D. Ingebo Washington, NASA, Jul. 1966 22 p refs
(NASA-TN-D-3513) CFSTI: HC $1.00/MF $0.50 CSCL 21H

Drop-size-distribution data were obtained for jets of ethanol atomized by downstream injection from a simple orifice into a combustion-gas stream inside a rocket combustor. High-frequency acoustic oscillations were induced in the combustor by a siren exhaust system. A high-speed camera was used to obtain photomicrographs of the ethanol sprays at several distances downstream from the injection-tube orifice and over a range of amplitude variations in the acoustic oscillations produced by the siren at a fixed frequency of 1190±5 cps. From the photomicrographs, the volume-number mean drop diameter D_{30} was calculated by direct integration of the drop-size data and compared with values of D_{30} obtained from the Nukiyama-Tanasawa expression for drop-size distribution. The results showed good agreement. Fine atomization was obtained with the siren exhaust system. Also, the atomization process was more rapid with the siren operating. Complete breakup occurred 1 in. downstream from the injector-tube orifice, whereas without the controlled oscillations, 6 in. were required. Similarly, the distance required for relatively complete vaporization was 2 in., whereas, without such oscillation, more than 2 ft were needed. Values of D_{30} determined under "resonant" combustion conditions agreed fairly well with the expression derived for crosscurrent breakup of liquid jets in airstreams.

N66-30181, 17-33

33. Jenkins, D. C.

A66-42053
THE TIME REQUIRED FOR HIGH SPEED AIRSTREAMS TO ATOMIZE WATER DROPS.
D. C. Jenkins (Ministry of Aviation, Royal Aircraft Establishment, Farnborough, Hants., England).
IN: APPLIED MECHANICS; PROCEEDINGS OF THE ELEVENTH INTERNATIONAL CONGRESS OF APPLIED MECHANICS, MUNICH, WEST GERMANY, AUGUST 30-SEPTEMBER 5, 1964. [A66-41934 23-23]
Edited by Henry Görtler.
Berlin, Springer-Verlag, 1966, p. 1094-1100. 7 refs.

Experimental investigation of the atomization of water drops by means of a technique developed to facilitate the study of the progress of atomization with time and the determination of the point where atomization can be said to be complete. Of the postulated mechanisms considered, the wave mechanism appears to be the most promising. By its use, a relationship for the time of atomization was deduced which is approximately of the same form as the relationship derived from tests between the time, the initial drop diameter, and the airstream velocity. A prediction of drop size was made which is in quite good agreement with the average drop sizes found in the one case studied.

A66, 42053, 23-02

34. Jenkins, D. C. and J. D. Booker

N66-22790# Aeronautical Research Council (Gt. Brit.)
THE TIME REQUIRED FOR HIGH SPEED AIRSTREAMS TO DISINTEGRATE WATER DROPS
D. C. Jenkins and J. D. Booker London. HMSO. 1965 85 p refs Supersedes RAE-TN-MECH-ENG-401; ARC-26531 (ARC-CP-827; RAE-TN-MECH-ENG-401; ARC-26531) CFSTI: HC $3.00/MF $0.75

The time required for high speed airstreams to disintegrate water drops has been determined experimentally, and an empirical relation found between the time, the airstream velocity and the drop diameter. The acceleration of drops during disintegration has also been found and an empirical relationship derived. The equation of motion of a disintegrating drop has been considered and a drag coefficient determined which gives a drop motion agreeing reasonably well with that found experimentally in a particular case. Droplets produced during disintegration have been measured in a particular case and compared with the sizes that would be expected if some of the proposed mechanisms of disintegration were operative. It has not been found possible to determine conclusively what mechanism operates to cause disintegration, but the evidence favors a wave-making mechanism.

N66-22790, 12-01

35. Kaura, N. N. and M. N. Rao

6483. Kaura, N. N., and Rao, M. N., Flow pattern of a liquid on a vaned disk atomizer, *Indian J. Technol.* 3, 1, 8-10, Jan. 1965.

Disk, 2¼-in. diam with 12 vertical radial vanes, was rotated at up to 12,000 rpm. Water feed rates ranged from 0.5-2.5 lb/min. Area of vanes wetted was obtained by observing the wash-off of a magnesium oxide film on the vanes.

Wetted area on leading face was always greater than on trailing face. At constant feed rate, wetted area at first increased rapidly with rotational speed, then decreased. The speed giving maximum wetted area decreased with increase of feed rate.

Reviewer considers an attempt should have been made to discover if the observed effects have any bearing on atomization performance. If not, the value of the study is obscure.

AMR18-6483

36. Kelly, D. P.

"Measurements of Drop Size Distributions in Natural Clouds and Rain" Massachusetts Inst. of Tech., Contract No. AF19(628)-4085, Final Report, AD 630 706, March 31, 1965.

37. Klüsener, O.

Zum Einspritzvorgang in der kompressorlosen Dieselmaschine (On the injection process in solid injection Diesel engines). O. Klüsener (Tech. Hochsch. Hannover, Germ.). VDI-Z. (Germ.) Vol. 77, No. 7 (Feb. 1933), pp. 171-172, 8 fig. Reprinted in: Dieselmasch. VI (Germ.), 1936, pp. 5-6, 8 fig.

38. Krasnov, A. N.

"Plasma Jet Atomization of Molybdenum" Poroshkovaya Metall. No. 3, 1965, pp. 1-5.

39. Langer, G.

1695 **AN ACOUSTIC PARTICLE COUNTER—PRELIMINARY RESULTS.** C. Langer.
J. Colloid Sci. (USA), Vol. 20, No. 6, 602-9 (Aug. 1965).

The detection of dust particles in air by an acoustic phenomenon is described. The particles are passed through a sensor in which they are gradually accelerated to about 100 m/sec and then the particles are suddenly projected into a wide exit cavity. At this point a pressure pulse is generated by a particle and gives an audible click. The sound pulse lasts 2 to 20 msec, depending on the entrance design, and has an optimum signal-to-noise ratio of 50/1. This sensor in its present state detects particles down to 5 microns with no change in signal amplitude with size. It has been applied in the laboratory to count ice crystals in supercooled clouds.

PA69-1695

40. Lastovtsev, A. M. and N. I. Deryabin

"Experimental Determination of the Size of the Jets of Rotating Sprayers in a Stagnant and Moving Gas" Tr. Mosk. Inst. Khim. Mashinostr. 26, 113-30 (1964). CA 62-15776g

41. Lindblad, N. R. and J. M. Schneider

"Production of Uniform-Sized Liquid Droplets"
J. Sci. Instr. 42, 635-8 (Aug. 1965).

A method for producing a stream of uniform-sized liquid droplets and individual droplets is discussed in detail. The method is based on the principle that a cylinder of liquid (jet) is dynamically unstable under the action of surface tension. When a capillary wave of a prescribed wavelength is applied to the jet, the jet will disintegrate into a stream of uniform-sized droplets. Since the droplet size depends on the capillary tube through which the liquid flows, the size can be easily varied. A piezoelectric transducer is used to produce the capillary wave on the jet. The apparatus discussed will produce droplets in a range between 25 and 350 μm in radius. The method is unique in that the droplet size can be precisely controlled and individual droplets can be produced at will. Author

42. Manfré, G.

"Rheological Aspects of Drop Formation"
J. Appl. Phys. 37, No. 5, 1955-62
(April 1966).

43. Marshall, B. S.

"An Improved All-Glass Fluid-Feed Atomizer"
J. Sci. Instr. 43, No. 3,
199-200 (1966)

CA 64-10774g

44. Mason, B. J.

A66-36622 #
THE COLLISION, COALESCENCE, AND BOUNCING OF SMALL WATER DROPS.
B. J. Mason (London, University, Imperial College of Science and Technology, London, England).
IN: INTERNATIONAL CONFERENCE ON CLOUD PHYSICS, TOKYO AND SAPPORO, JAPAN, MAY 24-JUNE 1, 1965, PROCEEDINGS. [A65-36603 24-20]
Conference sponsored by the International Association of Meteorology and Atmospheric Physics of the International Union of Geodesy and Geophysics, World Meteorological Organization, Science Council of Japan, and the Meteorological Society of Japan Tokyo, Meteorological Society of Japan, 1965, p. 162-107. 9 refs.

Experimental investigation of collection and collision efficiencies, coalescence, and bouncing of small water drops. It is noted that the agreement found between experimental collection efficiencies and calculated collision efficiencies strongly suggests that collisions between droplets of the size examined are nearly always followed by coalescence, and that bouncing off rarely occurs. This was confirmed by photographing the interaction of an airborne stream of uniform, equally spaced droplets with a similar stream of droplets of different size and also by high-speed photography of colliding pairs. A simplified theory for the motion of a drop rebounding from the water surface yields expressions for the depth of the crater and the restoring force at any stage and for the time of contact and the energy lost during impact. The computed values of these parameters are in reasonable accord with experiment. If the drop is to coalesce with the water surface, it must first expel and rupture the intervening air film. If the film has to reach a certain minimum thickness before coalescence can occur, the theory predicts that the greater the radius and impact velocity of the drop, the more difficult will coalescence be, because the film is less likely to attain this minimum thickness during the period of contact. These predictions are confirmed by the observations, but there are departures for drops striking at nearly glancing incidence and for large energetic drops striking nearly normally. Relatively large drops, of radius greater than about 150 μ, impinging nearly normally on the water surface, are considerably deformed during impact. The effective area of the trapped air film may now be confined to a narrow annular ring, making for more rapid draining of the film and easier coalescence. Since the deformation is greater for larger drops striking at higher velocities, it follows that larger drops should have smaller critical velocities for coalescence. This was observed to be so. The experimental values of collection efficiency are tabulated. A65-36622, 24-20

45. Masters, K.

"The Theory and Practice of Atomization in Spray Drying" Birmingham Univ. Chem. Eng. 17, No. 1, 18-24 (1966).

46. Masuda, S-I., T. Onishi, and H. Saito

"Inlet-Gas Humidification System for an Electrostatic Precepitator" I & E.C. Process Design and Development 5, No. 2, 135-45 (April 1966).

47. May, K. R.

"Spinning-top Homogeneous Aerosol Generator with Shockproof Mounting"
J. Sci. Instr. 43, 841-2 (1966)

48. Mumma, V. R. et. al.

AD-636 958 Fld. 7/4, 14/2
ARMY BIOLOGICAL LABS FREDERICK MD
A PARTICLE SIZE ANALYZER FOR AEROSOLS.
by Victor R. Mumma, Albert L. Thomas Jr. and Robert H. Collins III. 1962. 12p.
Unclassified report

Prepared in cooperation with Southern Research Inst., Birmingham, Ala.

Availability: Published in Annals of the New York Academy of Sciences v99 art2 p298-308 29 Jun 1962.

Descriptors: (*Aerosols, *Particle size), Instrumentation, Geometric forms, Light, Scattering, Air pollution

An instrument for counting and sizing aerosolized particles is described. It is based on the observation of scattered light as the particles pass through an illuminated area. The application of the device to the study of particle shape is described, and its application to practical uses is indicated. (Author)

TAB66-18

49. Norgren, C. T. and D. S. Goldin

A64-24644
EXPERIMENTAL ANALYSIS OF THE EXHAUST BEAM FROM A COLLOID THRUSTOR.
Carl T. Norgren and Daniel S. Goldin (NASA, Lewis Research Center, Cleveland, Ohio).
American Institute of Aeronautics and Astronautics, Electric Propulsion Conference, 4th, Philadelphia, Pa., Aug. 31-Sept. 2, 1964, Paper 64-674. 12 p. 11 refs.
Members, $0.50; nonmembers, $1.00.

Report of operation of a homogeneous-condensation type of colloid thrustor, using mercurous chloride propellant and with accelerating voltages up to 18 kv. The exhaust beam has been analysed with a unique quadrupole mass filter, which detected a single high-intensity particle spectrum with a mass distribution of 0.72 x 10^7 to 1.38 x 10^7 atomic mass units per unit electron charge (amu/z) when the propellant flow was in the continuum flow regime. It was estimated that a loss in overall thrustor efficiency of less than 2% would be incurred due to this narrow particle spectrum. A low intensity of charged particles over the range of about 10 to 1 x 10^3 amu/z was detected when the flow was in the slip-flow regime. No colloids were detected when the propellant flow was in the free-molecular regime. A theoretical study based on the liquid-drop theory of nucleation was used to correlate the colloid formation behavior, and the data taken in this program are also compared with previous data. It is shown that homogeneous condensation could provide the narrow amu/z distribution required for a high-performance electrostatic rocket.

A64-24644, 20-27

50. Nottage, H. B. and L. M. K. Boelter

"Dynamic and Thermal Behavior of Water Drops in Evaporative Cooling Processes" Heating, Piping, and Air Conditioning 12, 326-32 (May 1940).

51. Pfeifer, R. J.

N65-32107# Thiokol Chemical Corp., Denville, N. J. Reaction Motors Div.
THE GENERATION OF CHARGED COLLOIDS FOR ELECTRIC PROPULSION VIA HETEROGENEOUS CONDENSATION IN VACUUM OF METAL VAPORS ON A SURFACE
Final Report, 20 Jun. 1960–19 Dec. 1963
Bernard Hornstein Mar. 1964 42 p refs
(Contract AF 49(638)-924)
(RMD-2049-F; AFOSR-65-0925; AD-617120)

Efforts to define a process for generating charged colloids useful for electric propulsion were not successful. Emphasis was placed upon the formation of particles by condensing metal vapors upon a solid surface in a vacuum. This was followed by a step where an applied electrostatic field would inductively charge the particles and apply a force to overcome the adhesion between particle and substrate. The limitation proved to be particle removal; quantitative and reliable particle removal was not accomplished at imposed V/d values of 3.5 X 10^7 Vm^{-1}. Although most of the removal experiments were upon the lead-carbon system, it can be expected that other systems with interfacial adhesion one, two, or three orders lower than Pb/C would be exceptional, and that electrostatic removal would be difficult

N65-34471, 22-25

52. Pilcher, J. M. and C. W. Rodman

"An Apparatus for Studying the Effect of Drop Size on Flame Stability of Fuel Mists" Battelle Memorial Inst. Contract No. AF33(038)-12656, Tech. Report No. 15032-1, August, 1953.

53. Popov, V. F. and G. K. Goncharenko

AD-629 414 Fld. 14/2, 20/4
CFSTI Prices: HC $1.00 MF $0.50
FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OHIO
INVESTIGATION OF ULTRASONIC ATOMIZERS OF LIQUIDS AND MELTS,
by V. P. Popov, and G. K. Goncharenko. 20 Jan 66, 12p. Rept. no. FTD-TT-65-1443,
TT 66-60720

Unclassified report

Unedited rough draft trans. of Khimicheskaya Promyshlennost (USSR) n6 p442-5 1964.

Descriptors: (*Liquids, Atomization), (*Atomization, Ultrasonic radiation), Theory, Drops, Heat transfer, Mass transfer, Sprays, USSR, Liquid metals

It was experimentally shown that the distribution of particles in the spray with respect to their diameter in the aggregate has a continuous character under the most diversified conditions of atomization. Therefore, the obtained system of drops can be examined as a static aggregate.

TAB 66-8

54. Ramshaw, C.

AD-636 972 Fld. 14/2, 21/8.1
CFSTI Prices: HC $1.00 MF $0.50
ROCKET PROPULSION ESTABLISHMENT WESTCOTT (ENGLAND)
TECHNIQUES FOR DROP SIZE MEASUREMENT BY DIRECT PHOTOGRAPHY AND ELECTRONIC PARTICLE SIZE ANALYSIS.
Technical rept.
by C. Ramshaw. Dec 65, 24p. Rept. no. RPE-TR-65/9.

Unclassified report

Descriptors: (*Sprays, Particle size), (*Droplets, Measurement), Photographic analysis, Photographic images, Optical equipment, Fuel sprays, Combustion chambers, Rocket motors (Liquid propellants), Great Britain

A photographic technique is described which overcomes many of the problems encountered in measuring the droplet size distribution in sprays. Droplet photographs were analysed using a Mullard Particle Size Analyser as recommended in the text and it is shown that, for photographs in which the depth of field is less than the spray thickness, a high contrast emulsion leads to errors. In general it is better to avoid out-of-focus drops, but a method is suggested which permits the results to be corrected provided the extent of the spray is large compared to the depth of field. (Author)

TAB66-18

55. Rice, E. J.

N66-31238# Wisconsin Univ., Madison.
THE EFFECT OF SELECTED FLUID PARAMETERS ON SPATIAL DROP SIZE DISTRIBUTION
Edward Junior Rice (Ph.D. Thesis) 1966 290 p refs

A fluorescent technique for studying microscopic properties of a fluid is described, along with the apparatus, its alignment and calibration. Extremely fine spatial resolution is obtained by using a high intensity sheet of radiation intersecting the spray at 75° and having a uniform thickness of 0.2 mm. Droplets of the fluid, containing fluorescent dye, absorb radiation from the radiation sheet. The high resolution camera has a 25 magnification and resolves a 10 micron drop with less than 10% error. A modified spot counter is used to size the photographed drops. Data is presented at six adjacent radial positions for ethanol at 40, 70, and 100 psig; 50% glycerol-50% water at 130, 170, and 210 psig; and 65% glycerol-35% water at 170, 210, and 250 psig. It was found that the maximum drop size could be used to describe the drop size distribution. The maximum drop size was correlated with the fluid properties, nozzle pressure, and position in the spray.

N66-31238, 17-33

56. Roberts, J. H. and M. J. Webb

"Measurement of Droplet Size for Wide Range Particle Distributions" AIAA Journal 2, No. 3, 583-5 (March 1964).

57. Roulston, W. J. and H. J. Schnitzerling

"Relation of the Formation of Cattle Sprays to the Deposition and Loss of DDT" J. Sci. Fd. Agric. 16, 179-185 (April 1965).

58. Ryce, S. A. and D. A. Patriarche

7785 ENERGY CONSIDERATIONS IN THE ELECTROSTATIC DISPERSION OF LIQUIDS. S. A. Ryce and D. A. Patriarche. Canad. J. Phys., Vol. 43, No. 12, 2192-9 (Dec. 1965).

For the dispersion of electrically surface charged liquid drops it is assumed that the final minimum energy state is accessible to the system. Asymmetric division into two drops of radius r and xr is considered as well as symmetric dispersion into n droplets of equal radius, where n = 2, 3, 4. A parameter y is defined as $y = Q^2/(16\pi R^3\gamma)$, where Q is the charge on the original drop of radius R and surface tension γ. It is shown that if $x > 2$ in an asymmetric binary division, the smaller of the two droplets formed may be unstable and divide again. Photographic evidence of a secondary division is given. For a symmetric dispersion, at $y = 1$, the formation of four droplets leads to an energy minimum with a maximum number, n_{max}, of allowed droplets of 20. For values of $y > 1$, n_{max} rises sharply. Values of y are calculated, below which symmetric division into two, three, or four droplets is forbidden. The conclusion is reached that below $y = 0.351$ the only permitted process is asymmetric division into two droplets, and that there is no situation for which binary symmetric division leads to a lower final energy of the system than the other modes of dispersion.

PA69-7785

59. Sample, S. B.

N65-33439# Illinois Univ., Urbana. Charged Particle Research Lab.
STATIC AND DYNAMIC BEHAVIOR OF LIQUID DROPS IN ELECTRIC FIELDS
Steven B. Sample Jun. 1965 81 p refs Sponsored by NSF (CPRL-7-65)

The problem considered is the behavior of an uncharged, conducting liquid drop in a uniform electric field. The liquid is assumed to be homogeneous, non-viscous, and incompressible. The shape of the drop is expressed as an infinite series of Legendre polynomials, and expressions, correct to second order in the Legendre polynomial coefficients, are obtained for the surface tension potential energy and electrostatic potential energy of the system. The total system potential energy is then minimized with respect to variations in the coefficients, thereby yielding the equilibrium shape of the drop in a d-c field. This theoretically predicted drop distortion is shown to be in close agreement with all experimental data. The coefficients are then considered to be time varying, and a second order expression for the kinetic energy of the liquid is obtained. This expression is combined with the total potential energy to yield the Lagrange formulation of the equations of motion for the coefficients.

N65-33439, 21-23

60. Schůrek, O.

A66-25076 #
ATOMIZATION OF FLUID [ROZPRAŠOVÁNÍ KAPALINY].
Oldřich Schůrek.
(Českomoravská Kolben-Daněk a Státní Výzkumný Ústav Tepelné Techniky, Konference o Turbokompresorech, Prague, Czechoslovakia, Sept. 9-Oct. 2, 1964.)
Zpravodaj VZLÚ, no. 5, 1965, p. 23-32. 9 refs. In Czech.

Analysis of the atomization process using nozzles and rotating disks. Physical laws governing the atomization of fluids are reviewed, and the main relationships for the determination of the principal characteristics of atomization systems are given. An experimental method for the determination of these characteristics is also included. The method of atomization using nozzles is then compared with the method using rotating disks, and examples of atomizing systems designs are included. The comparative analysis shows that for bladed machines, the method using simple rotating disks is preferable.

A66-25076, 13-12

61. Semonin, R. G. and H. R. Plumlee

A65-36625 #
THE EFFECT OF ELECTRIC CHARGES AND FIELDS ON THE COLLISIONS OF VERY SMALL CLOUD DROPS.
M. H. Davis (RAND Corp., Santa Monica, Calif.).
IN: INTERNATIONAL CONFERENCE ON CLOUD PHYSICS, TOKYO AND SAPPORO, JAPAN, MAY 24-JUNE 1, 1965, PROCEEDINGS. [A65-36603 24-20]
Conference sponsored by the International Association of Meteorology and Atmospheric Physics of the International Union of Geodesy and Geophysics, World Meteorological Organization, Science Council of Japan, and the Meteorological Society of Japan.
Tokyo, Meteorological Society of Japan, 1965, p. 118-120. 7 refs.
Discussion of the influence of electric charges and fields on collisions of small cloud droplets using accurate electrostatic forces (Davis, 1962, 1964) and recently improved values for hydrodynamic forces. Of primary interest are cases when collisions will occur only under the influence of electrostatic forces (Sartor, 1960). The results are based on the numerical integration of droplet trajectories. Using Hocking's hydrodynamics it was estimated that electrostatic forces began to produce collisions in droplets with radii under 15μ under certain conditions. The effect was most important when the droplets were nearly the same size.

A65-36624, 24-20

62. Silverman, B. A.

"A Laser Fog Disdrometer" J. Appl. Meteorol. 3, 792-801 (Dec. 1964).

63. Tamada, K. and Y. Shibaoka

"On the Penuant Drop. I" J. Phys. Soc. Japan 16, No. 6, 1249-52, (June 1961).

64. Taylor, G.

A66-26301 #
THE FORCE EXERTED BY AN ELECTRIC FIELD ON A LONG CYLINDRICAL CONDUCTOR.
Geoffrey Taylor.
Royal Society (London), Proceedings, Series A, vol. 291, Apr. 5, 1966, p. 145-158.
The calculations and experiments here described were undertaken in the hope of giving a rational description of the fine jets which a strong electric field can drag from the surface of a conducting fluid. The force on a long axisymmetric conductor in contact with a conducting plane and subjected to an electric field parallel to its length is found by replacing the conductor by an axial distribution of charge. This distribution can be determined by means of an integral equation. The solutions for some particular cases were found by means of a computer, and van Dyke, in an appendix, gives a more analytical method of solution. The equivalent distribution of charge is found for half a spheroid standing on a plane. The force acting on this distribution is compared with the known force on the curved surface of a hemispheroid and the result used to show that the error involved in taking them as equal is small. Experiments are described in which cylinders and hemispheroids standing on a horizontal earthed plate were lifted by a vertical field. Agreement between these experiments and calculation when the conductors are sufficiently light indicates that the space charge in the intense field at their upper ends is not large enough to invalidate the calculation, but when the conductors are heavy enough they oscillate instead of rising, an effect which must be due to electric breakdown of the air producing space charges which upset the field.

A66-26301, 13-24

65. Taylor, G., et. al.

17901 STUDIES IN ELECTROHYDRODYNAMICS. I. THE CIRCULATION PRODUCED IN A DROP BY AN ELECTRIC FIELD. G. Taylor; A.D. McEwan and L.N.J. de Jong.
Proc. Roy. Soc. A (GB), Vol. 291, No. 1425, 159-66 (1966).
The elongation of a drop of one dielectric fluid in another owing to the imposition of an electric field has previously been studied assuming that the interface is uncharged and the fluids at rest. For a steady field this is unrealistic, because however small the conductivity of either fluid the charge associated with steady currents must accumulate at the interface till the steady state is established. It is shown that equilibrium can only be established in a drop when circulations are set up both in the drop and its surroundings. A relation is found between the ratios of the conductivity, viscosity and dielectric constant for the drop and surrounding fluid which permits the drop to remain spherical when subjected to a uniform field. The streamlines of the circulation for this case are shown and criteria are given for distinguishing between circulations which carry the surface of the drop towards or away from the poles and for predicting whether the drop will become prolate or oblate. Experiments by Mason and his co-workers are compared with the theoretical predictions and agreement is found in all cases for which the necessary data are given.

PA69-17901

66. Tovbin, M. V., O. A. Panasyuk, and L. N. Oleinik

"Critical Dimensions of Disintegrated Liquid Droplets" Kolloidn. Zh. 27, No. 4, 609-13 (1965).

CA63-14069f

67. Ul'yanov, I. Ye. and N. S. Lamekin

N66-20570# Air Force Systems Command, Wright-Patterson AFB, Ohio Foreign Technology Div
LIQUID FUEL INJECTOR
I Ye Ul'yanov and N S Lamekin 28 Sep 1965 7 p Transl into ENGLISH from Russian Patent no 123375 (Appl no 578744/25, 12 Jan 1956) 2 p
(FTD-TT-65-1011/1+2+4; AD-627068) CFSTI HC $1.00/MF $0.50
A fuel injector which uses ultrasonic vibration to assure atomization is presented. The atomization process is independent of the fuel feed pressure. A pneumatic generator in the form of a volumetric resonator provided with a slit acts as the ultrasonic vibrator.

N66-20570, 10-28

68. Woffinden, G. J.

N66-30506# Aerojet-General Corp., Downey, Calif.
INVESTIGATION OF THE COALESCENCE OF WATER DROPS Final Report, 15 Feb. 1965–14 Feb. 1966
G. J. Woffinden Ft. Monmouth, N. J., Army Electron. Command, Apr. 1966 37 p refs
(Contract DA-28-043-AMC-00497(E))
(ECOM-00497-2; AD-632415) CFSTI: HC $2.00/MF $0.50

Experimental techniques have been developed for producing uniform water drops from 25 to 500 microns in diameter. The droplets are formed from a pressure modulated water jet as it passes through a tiny orifice. Orifices with diameters as small as 20 microns have been used. The water pressure is modulated at approximately 160,000 cps for the smallest droplets. The harmonic vibration of the transducer provides a stream of reproducible droplets at controllable intervals. The drop generator was designed for use in studying the coalescence of cloud and fog-size water droplets under various environmental conditions, and high-speed photographic techniques were developed to measure coalescence delay times.

N66-30506, 17-12

69. Yugai, F. S. and B. P. Volgin

17842 QUALITATIVE POSTURE OF LIQUID MOTION IN AN ACCELERATING GAS FLOW.
F. S. Yugai and B. P. Volgin.
Inzhen.-Fiz. Zh. (USSR), Vol. 9, No. 6, 703-6 (6 Dec. 1965). In Russian.

The behaviour of liquid drops in an energized gas flow is investigated by means of a high-speed photographic shooting. The photos of liquid drops taken at different points along the gas flow of different velocities are presented in the paper. It is found that the major part of energy is spent for elastic strain followed by crushing the drops, but not for speeding them up to the gas-flow velocity.

PA69-17842

70. Zinky, W. R.

"Hologram Camera and Reconstruction System for Assessment of Explosively Generated Aerosols" Edgewood Arsenal, CRDL, Contract No. DA-18-035-AMC-256(A), Report No. TO-B-65-90, Ad 474 534, Oct. 7, 1965.

APPENDIX C

REMARKS ON THE LITERATURE

[redacted]

In attempting to correlate the results of various investigators, it was difficult at times to establish the exact intent of the author because of problems in semantics, the use of unfamiliar conventions, or inadequate descriptions. In order to assist any future reviewers, the following discussion covers some of the specific problem areas encountered during this investigation.

Japanese Literature. The Japanese authors (specifically Tanasawa and co-workers) commonly use a metric gravitational counterpart to our English system of units, using meters, kilograms force, and seconds. The fact that they do not distinguish between kilogram mass and kilogram force raises problems in establishing conversion factors if one does not know whether a given equation is dimensionally consistent or not.

The units commonly used by the Japanese together with their equivalent in an absolute system are listed below. Although the Japanese authors do not so specify, the distinction between kilogram force (kgf) and kilogram mass (kgm) is made in the following:

Fluid density (actually specific weight),
  kgf/m^3 = $\rho(g_L/g_c)$

Fluid viscosity:
  Absolute, (kgf) (sec)/(m)^2 = μ/g_c

  Kinematic, m^2/sec = $\nu = \mu/\rho$

  Surface tension, kgf/m = σ/g_c

  Pressure, kgf/m^2 = p/g_c .

The symbols given above as equivalents are defined in the "Nomenclature." However, the absolute MKS system of units should be used in the above equalities (instead of the cgs units given in the "Nomenclature").

British Literature. The British use a term which they call "Flow Number" defined by the following equation with the specific units indicated:

$$FN = q_j/\sqrt{\Delta p} \quad , \tag{C-1}$$

where

q_j = liquid flow rate, British Imperial gallons/hr

Δp = pressure drop across nozzle, psi .

This number is basically a measure of nozzle capacity. The following gives the conversion in terms of cgs units:

$$FN = 208q_j/\sqrt{\Delta p} \quad , \tag{C-2}$$

where

q_j = liquid flow rate, cu cm/sec

Δp = pressure drop across nozzle, dynes/sq cm .

The British also use a discharge coefficient, C_q, which is identical to the dimensionless coefficient used in most fluid mechanics literature and is defined by

$$C_q = (q_j/A_j)\sqrt{\rho_j/2\Delta p} \tag{C-3}$$

where in any consistent system of units

q_j = liquid flow rate

A_j = nozzle area

ρ_j = liquid density

Δp = pressure drop across nozzle.

The discharge coefficient, C_q, is also identical to the quantity $1/\sqrt{N_{vj}}$.

Russian Literature. Some Russian literature has used metric gravitational units, similar to the Japanese usage. However, in some instances the kilogram has been used to denote both a mass and a force. This usage is synonymous with equating g_L and g_c (both numerically and dimensionally) when using the type of conversions previously given for the Japanese literature. This makes it very difficult to decide whether or not an equation is dimensionally homogeneous or not.

General. Some authors apply the same name to power functions of a dimensionless ratio. This is especially true in the case of the Weber number. The Weber number is commonly defined as $Du^2\rho/\sigma$ but is sometimes defined as the square root of this, *i.e.*, $u\sqrt{D\rho/\sigma}$. Similarly, the Froude number is usually $u^2/g_L D$ but is sometimes defined as $u/\sqrt{g_L D}$.

One must also be on the lookout for variations in the definitions of the dimensionless groups involving factors of integers or the value π. The use of a radius in place of a diameter is quite common.

NOMENCLATURE

(Glossary)

Except where specifically noted otherwise, all equations in the text are written in a dimensionally consistent form so that any consistent system of absolute units may be employed. The cgs system is given by way of example of a common absolute system in the following definition of terms. If it is desired to use a gravitational system of units, a conversion factor g_c must be added as a coefficient in the equations each time a term involves a force (*e.g.*, replace Δp with $g_c\Delta p$; replace $1/\Delta p$ with $1/g_c\Delta p$; or replace σ with $g_c\sigma$).

Where a symbol is used alone (as in a table or figure), any unit may be designated. Where no units are designated in those cases, this factor is either of no significance at that point or those specified in the "Nomenclature" are to be used.

a = acceleration, due to a force field, cm/sec^2

a_d = acceleration at tip of disk, cm/sec^2

A_g = total pneumatic-nozzle gas-phase discharge-opening area available for flow, sq cm

A_i = total area of liquid inlet to swirl-chamber, sq cm

A_j = total liquid-phase jet (hydraulic) discharge-opening area available for flow, sq cm

A_{ja} = actual apparent area through which liquid flows at swirl nozzle discharge-opening (*i.e.*, A_j minus area of air core), sq cm

A_o = nozzle discharge-opening area, sq cm

A_p = surface area of a drop or particle, sq cm

A_{pp} = area of particle projected on a plane normal to direction of flow, sq cm

c = velocity of sound in gas phase, cm/sec

C_D = drag coefficient, dimensionless = $F_D/(A_{pp})(\rho_g u_r^2/2)$

C_q = discharge coefficient, dimensionless

C_{xy} = constant for given correlation where x and y are the authors initials, dimensionless (where more than one constant is needed for an author, a numerical subscript is also added, *e.g.*, C_{xy1})

d = "derivative of"

D = characteristic dimension or diameter, cm

D_{ac} = diameter of the air core in the discharge opening of a swirl nozzle, cm

D_c = diameter of the swirl chamber in a swirl atomizer, cm

D_d = rotating disk diameter, cm

D_g = pneumatic-nozzle gas-phase discharge-opening diameter, cm

D_{ge} = effective gas-phase discharge-opening diameter, cm
= $\sqrt{4A_g/\pi}$

D_{go} = inside diameter of the largest tube in an annular-type pneumatic nozzle (see Fig. 2), cm

D_{g1} = smallest discharge opening diameter in an annular-type pneumatic atomizer (see Fig. 2), cm

D_j = diameter of the liquid phase discharge opening, cm

D_{je} = effective liquid-phase discharge-opening diameter, cm
= $\sqrt{4A_j/\pi}$

D_{jo} = outside diameter of the liquid-phase tube in a three-tube annular-type pneumatic nozzle (see Fig. 2), cm

D_{jw} = diameter of the wetted periphery between the liquid and gas phases in a pneumatic atomizer, cm

D_{lmv} = log median drop diameter on a volume basis, cm [defined by: $\ln D_{lmv} = \Sigma \ln D_p dm_{pp} / \Sigma\, dm_{pp}$]

D_{mn} = number median drop diameter, cm

D_{mv} = volume (mass) median drop diameter, cm

D_{mx} = undefined median drop diameter, cm

D_p = particle or drop diameter, cm

D_{pmax} = maximum drop diameter, cm

D_{qp} = $[\Sigma D_p^q dn_p / \Sigma D_p^p dn_p]^{1/(q-p)}$

D_{xx} = undefined mean or median drop diameter, cm

D_{10} = linear (arithmetic) mean drop diameter, cm

D_{30} = volume mean drop diameter, cm

D_{32} = Sauter (volume/surface) mean diameter, cm

e = natural logarithmic base, 2.718 ...

f = frequency of vibration in a vibrating atomizer, cycles/sec

F_D = total drag force acting on a particle, dynes

FN = "flow number," a term used in the British literature to measure nozzle capacity (specific units given in Appendix C)

g_c = conversion factor = 980.7 (g mass/g force)(cm/sec^2) [to be added only where a gravitational system of units is to be used]

G_g = mass velocity of the gas phase at the nozzle discharge opening (g)/(sec)(sq cm) = w_g/A_g

g_L = local acceleration due to gravity, cm/sec^2

G_j = mass velocity of the liquid (particulate) phase at the nozzle outlet, (g)/(sec)(sq cm) = w_j/A_j

k = dimensionless constant

k_g = factor for the additional effect of gas flow on drop size, dimensionless

k_{na} = factor for the effect of air core (cavity factor) in swirl nozzle, dimensionless

k_{ng} = factor for the effect of overall nozzle geometry on drop size, dimensionless

k_{nt} = correction factor for the type of nozzle, dimensionless

k_{pg} = factor for the effect of gas pressure on drop size, dimensionless

k_{qd} = factor for the effect of liquid film Reynolds number on spinning disk performance, dimensionless

k_q = factor for the effect of loading on drop size, dimensionless

k_r = factor for the effect of recombination of droplets, dimensionless

$k_{\mu j}$ = factor for the effect of liquid viscosity on drop size, dimensionless

$k_{\mu p}$ = factor for the effect of liquid viscosity on critical Weber number for drop breakup, dimensionless

K = dimensional constant

K_{xy} = dimensional constant where x and y are the initials of the authors presenting the correlation (where more than one constant is needed for an author, a numerical subscript is also added, *e.g.*, K_{xy1})

$\log_{10}$ = logarithm to base 10

ln = logarithm to base e

L = length, cm

L_b = jet breakup length, cm

L_f = thickness of liquid film at the disk periphery, cm

L_g = width of the annular air flow channel at the discharge of a pneumatic nozzle, cm

L_j = clearance between the primary air and liquid nozzles in a pneumatic atomizer (see Fig. 2), cm

L_{nj} = length of the discharge opening of a liquid nozzle, cm

L_r = radial distance between a spinning disk or cup lip and a surrounding annular gas jet, cm

L_w = wetted disk periphery per liquid stream discharged, cm/stream

m_p = mass of a single particle or drop, g

m_{pp} = mass of powder or collection of particles, g

n, n' = exponent, with subscripts referring to associated variable, dimensionless

n_p = number of particles, dimensionless

n_w = exponent on loading, dimensionless

N_{Bo} = Bond number, dimensionless = $g_L \rho D^2/\sigma$

N_{Ca} = capillary number, dimensionless = $u\mu/\sigma$

N_{Caj} = capillary number based on liquid phase properties, dimensionless = $u\mu_j/\sigma_j$

N_{Cajd} = capillary number based on the liquid phase properties and the disk velocity, dimensionless = $u_d\mu_j/\sigma_j$

N_{Cajj} = capillary number based in liquid phase properties and velocity, dimensionless = $u_j\mu_j/\sigma_j$

N_{Cajr} = capillary number based on liquid phase properties and relative velocity, dimensionless = $u_r\mu_j/\sigma_j$

N_{Fr} = Froude number, dimensionless = $u^2/g_L D$

N_{Frd} = Froude number based on spinning disk diameter and tip speed, dimensionless = $u_d^2/g_L D_d$

N_{Frj} = Froude number based liquid jet velocity and discharge-opening diameter, dimensionless = $u_j^2/g_L D_j$

N_{Ga} = Galileo number, dimensionless = $g_L D^3 \rho^2/\mu^2$

N_{Ma} = Mach number, dimensionless = u/c

N_{Oh} = Chnesorge number, dimensionless = $\mu^2/D\rho\sigma$

N_{Ohjd} = Ohnesorge number based on the liquid phase properties and spinning disk diameter, dimensionless = $\mu_j^2/D_d\rho_j\sigma_j$

N_{Ohjj} = Ohnesorge number based on the liquid phase properties and the liquid jet discharge-opening diameter, dimensionless = $\mu_j^2/D_j\rho_j\sigma_j$

N_{Ohp} = Ohnesorge number based on droplet diameter and properties = $\mu_p^2/D_p\rho_p\sigma_p$

N_p = gas pressure expressed as number of atmospheres absolute (refers to pressure of gas in atomization zone), dimensionless

N_{Re} = Reynolds number, dimensionless = $Du\rho/\mu$

N_{Regr} = Reynolds number based on gas properties, gas-phase, discharge-opening diameter, and relative velocity, dimensionless = $D_g u_r \rho_g/\mu_g$

N_{Reja} = Reynolds number based on liquid properties and apparent velocity, dimensionless = $D_j u_{ja} \rho_j/\mu_j$

N_{Rejd} = Reynolds number for a disk based on the liquid phase properties and the spinning disk velocity and diameter, dimensionless = $D_d u_d \rho_j/\mu_j$

N_{Rejj} = Reynolds number based on the liquid phase properties, the liquid jet velocity, and discharge-opening diameter, dimensionless = $D_j u_j \rho_j/\mu_j$

N_{Rejr} = Reynolds number based on the liquid phase properties and discharge-opening diameter and the relative velocity between phases, dimensionless = $D_j u_r \rho_j/\mu_j$

N_{Rep} = Reynolds number based on particle properties and relative velocity, dimensionless = $D_p u_r \rho_p/\mu_p$

N_{Repg} = Reynolds number based on particle diameter, gas properties, and relative velocity, dimensionless = $D_p u_r \rho_g/\mu_g$

N_{vj} = pressure drop through a nozzle orifice expressed as the number of average liquid velocity heads based on the discharge-opening area, dimensionless = $\Delta p/(\rho_j u_j^2/2)$

N_{vr} = pressure difference converted to effective kinetic energy expressed as a number of velocity heads, dimensionless = $\Delta p/(\rho_j u_r^2/2)$

N_{vz} = pressure drop expressed as the number of equivalent velocity heads, dimensionless = $\Delta p/(\rho u^2/2)$

N_{We} = Weber number, dimensionless = $Du^2\rho/\sigma$

N_{Weg} = Weber number based on particle diameter, gas properties and relative velocity, dimensionless = $D_p u_r^2 \rho_g/\sigma_p$

N_{Wegr} = Weber number based on s density, gas-phase discharge-opening diameter and relative velocity, dimensionless = $D_g u_r^2 \rho_g/\sigma_l$

N_{Wela} = Weber number based on liquid properties and apparent velocity, dimensionless = $D_l u_{la}^2 \rho_l/\sigma_l$

N_{Weld} = Weber number for a spinning disk based on the liquid phase properties and the disk velocity and diameter, dimensionless = $D_d u_d^2 \rho_l/\sigma_l$

N_{Well} = Weber number based on the liquid phase properties, the liquid jet velocity, and discharge-opening diameter, dimensionless = $D_l u_l^2 \rho_l/\sigma_l$

N_{Welr} = Weber number based on the liquid phase properties and discharge-opening and the relative velocity between phases, dimensionless = $D_l u_r^2 \rho_l/\sigma_l$

N_{Wep} = Weber number based on the particle properties and relative velocity, dimensionless = $D_p u_r^2 \rho_p/\sigma_p$

$(N_{Weg})_{cr}$ = critical Weber number for drop breakup, dimensionless = $(D_p u_r^2 \rho_g/\sigma_p)_{cr}$

$(N_{Weg})_{32}$ = value of N_{Weg} based on D_{32} for D_p, dimensionless = $D_{32} u_r^2 \rho_g/\sigma_p$

$(N_{Wep})_{32}$ = value of N_{Wep} based on D_{32} for D_p, dimensionless = $D_{32} u_r^2 \rho_p/\sigma_p$

p = pressure, dynes/sq cm

p_{vg} = velocity head of gas, dynes/sq cm = $\rho_g u_g^2/2$

p_{vl} = velocity head of liquid jet at liquid nozzle discharge opening, dynes/sq cm = $\rho_l u_l^2/2$

Δp = pressure drop across a nozzle or orifice, dynes/sq cm

q_g = volumetric flow rate of the gas (continuous) phase, cu cm/sec

q_l = volumetric flow rate of the liquid (particulate) phase cu cm/sec

t = time, sec

u = characteristic velocity, cm/sec

u_d = peripheral velocity (tip speed) of a spinning disk, cm/sec

u_g = gas phase velocity relative to nozzle at nozzle discharge opening, cm/sec

u_{gcr} = critical gas-phase velocity (see Plit, Table IV, point at which atomization mechanism changes), cm/sec

u_j = superficial average liquid velocity relative to nozzle based upon the total cross-sectional area of the liquid discharge opening, cm/sec = q_j/A_j

u_{ja} = average apparent liquid velocity in swirl nozzle discharge opening, cm/sec = q_j/A_{ja}

u_{jit} = average tangential component of velocity of the liquid at the inlet to a swirl nozzle, cm/sec

u_r = relative velocity between the liquid and gas phases (actual velocity that is effective in atomization); relative velocity between particles and fluid, cm/sec
= $|\vec{u}_g - \vec{u}_j|$, for simple hydraulic and pneumatic atomizers, cm/sec
= $(2\Delta p/\rho_j N_{vr})^{1/2}$ or $u_j(N_{vj}/N_{vr})^{1/2}$, for swirl nozzles or nozzles stationary with respect to ambient atmosphere in general, cm/sec. [For axial-flow nozzles stationary with respect to ambient atmosphere, as in simple or impinging jets, (N_{vj}/N_{vr}) = 1 and $u_r = u_j$.]

u_{rcr} = critical relative velocity required for drop breakup cm/sec

u_R = radial velocity in a spinning disk atomizer, cm/sec

u_s = particle surface regression velocity, cm/sec = $(1/2)(dD_p/dt)$

w_g = gas-phase mass flow rate, g/sec

w_j = liquid-phase mass flow rate, g/sec

x = "a variable"

Z = complex factor used by Nelson and Stevens (1961), (see Table III C), dimensionless

$\alpha,\beta,\gamma,\epsilon$ = exponents

Γ_j = liquid flow rate on a spinning disk per unit wetted disk periphery, (g)/(sec)(cm)

η_A = efficiency of atomization (fraction of applied energy converted into new surface energy), dimensionless

θ_{Dx} = total nozzle discharge-opening angle (angle included between the converging sides of a nozzle, radians) ($x = j$ for liquid phase opening; $x = g$ for gas phase opening; if the same, omit x)

θ_f = fan-spray angle, exit total angle (expanding) of nozzle discharge for fan spray nozzle, radians

θ_n = total angle of impingement for impinging jet atomizer (i.e., angle between axes of impinging jets), radians

θ_m = maximum total cone angle of the spray at the discharge opening of a spray nozzle, radians

θ_v = angle between vanes and plane normal to flow direction (or nozzle axis) in a swirl chamber, radians

μ = fluid (general) viscosity, poise

μ_g = continuous (gas) phase viscosity, poise

μ_l = discontinuous (liquid) phase viscosity, poise

μ_p = particle viscosity, poise

ν = kinematic viscosity, sq cm/sec = μ/ρ

π = constant of value 3.14159...

ρ = fluid (general) density, g/cu cm

ρ_g = gas (continuous) phase density, g/cu cm

ρ_l = liquid (discontinuous) phase density, g/cu cm

ρ_p = particle density, g/cu cm

σ = interfacial tension (general), dynes/cm

σ_l = liquid-gas interfacial tension, dynes/cm

σ_p = particle surface tension, dynes/cm

ψ = "function of"

ω = rotational speed, radians/sec

ω_d = rotational speed of disk, radians/sec

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13. ABSTRACT

A study was conducted to critically review and evaluate literature in the field of atomization. The literature survey yielded 955 pertinent references which have been summarized together with abstracts where available. The more important correlations presented in the literature for the various mechanical atomizing techniques (hydraulic or pressure, pneumatic or two-fluid, and rotary or spinning disk) have been summarized and analyzed. The best agreement was shown by the data for hydraulic swirl nozzles, where discrepancies were nominally not over twofold to threefold. The largest discrepancies, tenfold in some cases, were found for simple hydraulic nozzles. A large part of the discrepancy is attributed to shortcomings in the drop size analysis techniques, including sampling.

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